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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada

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CONVERSION FACTORS

Metric units in this report may be converted to inch-pound units by using the following conversion factors:

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound (lb)
kilometer (km)	0.6214	mile (mi)
kilopascal (kPa)	10	millibar (mbar)
meter (m)	3.281	foot (ft)
millimeter (mm)	0.03937	inch (in.)
millimeter per year (mm/a)	0.03937	inch per year (in/yr)
square kilometer (km^2)	0.3861	square mile (mi^2)
cubic meter (m^3)	35.31	cubic foot (ft^3)
degree Celsius (°C)	°F = 9/5°C + 32	degree Fahrenheit (°F)

SYMBOLS AND DEFINITIONS LIST

amberat - crystalized (dehydrated) packrat urine

AT - arboreal taxon (taxa)

^{14}C - radiocarbon, carbon-14; unstable isotope of normal carbon-12

Δ - relative change in a given parameter (for example, ΔT_a, change in mean annual temperature)

extralocal- a species not present in the vicinity of the site of its fossil occurrence

extralimital- a species not known to presently occur on a mountain mass where it is recorded as a fossil

equable - a temperature regime characterized by mild winter temperatures and a limited seasonal range of temperatures

full glacial- a widely-used synonym for the Wisconsin maximum

IS - Sorensen's similarity coefficient or index

N - number of identified taxa

NISP - number of identified specimens

N_{ts} - number of taxa of trees, shrubs, and succulents

P - precipitation (P_a, average annual precipitation; P_s, average summer precipitation; P_w, average winter precipitation)

percent P- percent change from present average value of precipitation

mesic - relatively moist (mesophytic, characteristic of relatively moist habitats)

pluvial - increased rainfall exceeding present annual values by at least 50 percent

paleonidology- the study of ancient packrat middens

σ - standard deviation

T - average value of temperature (T_a, average annual temperature; T_s, average summer temperature; T_w, average winter temperature)

percent T- percent change from present average value of temperature

thermophile- a species characteristic of sere (hot) habitats (thermophilous, with an afinity for sere habitats)

Wisconsin maximum - The period of greatest development of continental ice sheets in the Northern Hemisphere, about 18,000 years ago

xeric - relatively dry (xerophytic, characteristic of relatively dry habitats)

B.P. - radiocarbon years before present (1950). An age expressed in radiocarbon years before present is a statistical estimate of the remnant carbon-14 in a given sample and not directly equivalent to a sidereal or calendar year age

VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS IN THE VICINITY OF THE NEVADA TEST SITE, SOUTH-CENTRAL NEVADA

By W. Geoffrey Spaulding

ABSTRACT

Major changes in the climate of the Nevada Test Site have occurred during the last 45,000 years. Understanding this climatic variability is important in assessing the region's suitability for permanent nuclear-waste repositories. Future climatic changes probably will occur within the time the waste materials are hazardous. The nature and magnitude of previous fluctuations indicate the nature of future climatic change that may impact on a nuclear waste repository. Reconstructions of past vegetation are used to infer climatic conditions during the past 45,000 years. Plant macrofossils from ancient packrat (*Neotoma* spp.) middens provide the data for these analyses. Middens can be older than 50,000 years, and they are common in the region. Each contains abundant mummified plant fossils, representing the plant species growing within about 30 meters of the site. Radiocarbon-dated midden samples provide detailed records of climate-induced vegetation change.

During the Wisconsin glacial age, from at least 45,000 years ago to about 10,000 years ago, juniper (*Juniperus osteosperma*) woodland was widespread below elevations of 1,800 meters in the desert lowlands. Steppe shrubs were common, as were shrubs typical of the drier phases of current woodland. Late Wisconsin subalpine conifer woodland, typified by limber pine (*Pinus flexilis*), occurred at elevations above about 1,800 meters. Plants that are sensitive to frigid temperatures, and those restricted to moist habitats, are missing or are very rare in the glacial-age macrofossil record.

Development of desert vegetation in the lowlands of the Nevada Test Site and vicinity had begun by about 15,000 years ago. Timing of the vegetation change from woodland to desertscrub was transgressive. At higher elevation desert sites, woodland did not disappear until after about 8,000 years ago. The earliest records of desert vegetation in the vicinity of the Nevada Test Site appear to antedate those from the Sonoran Desert by at least 4,000 years.

Climatic conditions at about 45,000 years ago at the Nevada Test Site were similar to those of northern Nevada at present. Average annual temperature was at least 2° Celsius less than that of current average annual temperature. Summers were drier and colder, and winter precipitation may have exceeded current quantities by 20 percent. By about 30,000 years ago, annual temperature may have been 3° to 6° Celsius less than present values. The trend toward maximum glacial conditions appears to have been reversed briefly several times. By about 18,000 years ago, the relative decrease in annual temperature is inferred to have been 6° to 7° Celsius. Average summer temperatures were 7° to 8° Celsius cooler than those of the present, and winter precipitation exceeded present quantities by as much as 70 percent. There was a relative decrease in summer rainfall, and average annual precipitation probably did not exceed 40 percent of current quantities. Postglacial warming began as early as 16,000 years ago, and average annual temperatures probably approached present values by about 10,000 years ago. Differences exist between these paleoclimatic reconstructions and those that indicate a "pluvial" rainfall regime during the late Wisconsin. Temperatures appear to have been lower and rainfall less than the values proposed in models of an equable glaciopluvial.

Increased atmospheric carbon dioxide within the next 500 years probably will result in a 2° to 3° Celsius increase in annual temperature and intensified rainfall in the Nevada Test Site region. Analogs with previous glacial-interglacial cycles indicate that this "super interglacial" may be no more than a relatively brief reversal in the protracted trend toward the next ice age. Current models indicate that, within the next 10,000 years, climatic conditions may be similar to those of the last glacial age.

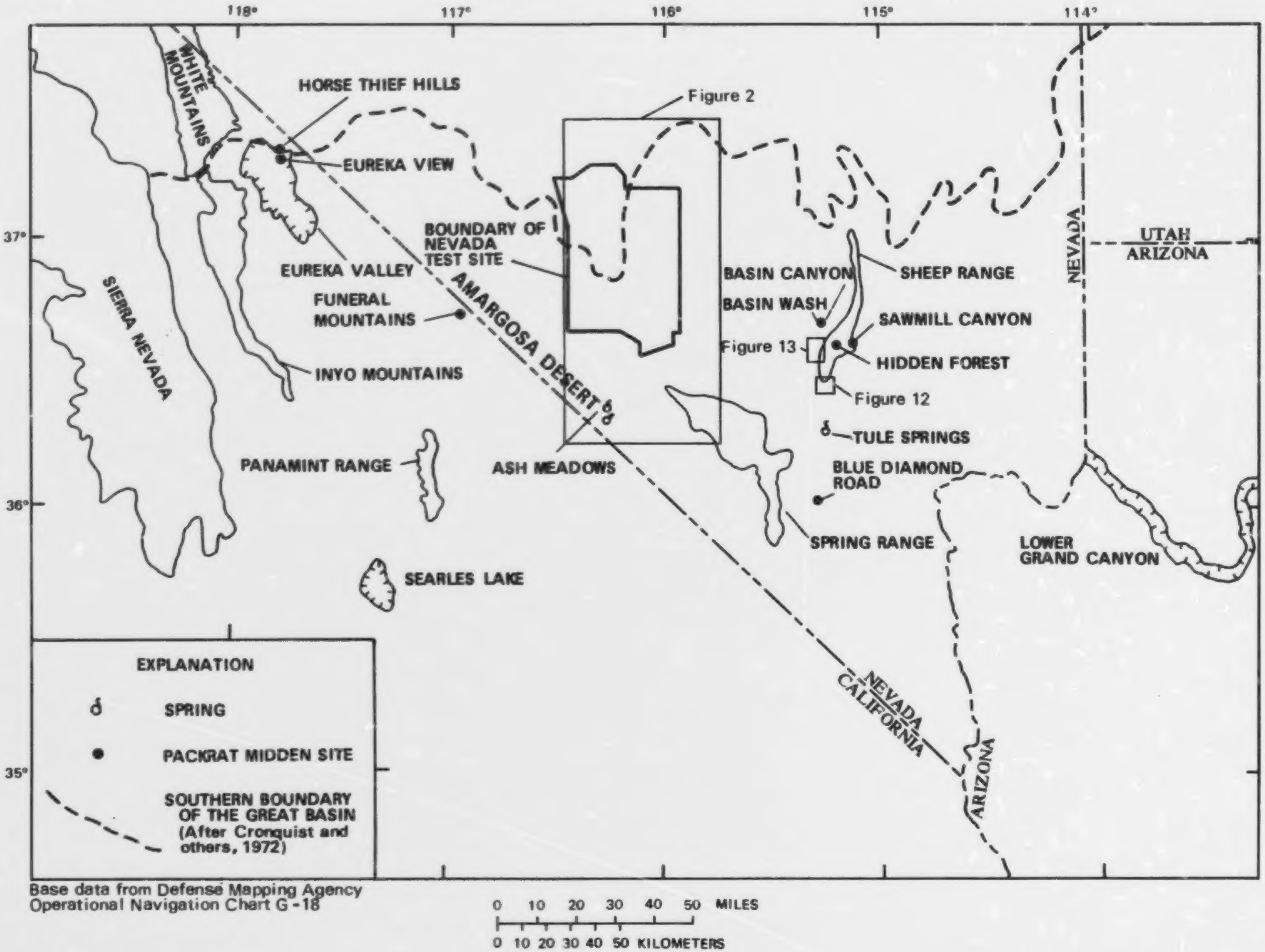
INTRODUCTION

A fundamental challenge presented by the use of nuclear energy is the safe, long-term disposal of both high-level and transuranic radioactive wastes. Proper storage of these materials, by-products of both commercial enterprises and nuclear weapons manufacture, requires isolation from the biosphere for a period exceeding their hazardous duration. Estimates of this duration range from 1,000 to 100,000 years (Winograd, 1981, p. 1458; Bredehoeft and others, 1978; Interagency Review Group, 1978). Such lengths of time encompass global climatic changes greater than those that have occurred in recorded history. To assure prolonged integrity of any nuclear-waste repository, long-term environmental stability of that site needs to be considered, and impact of future climatic change needs to be anticipated.

Major global climatic changes occur at regular frequencies of about 10,000 to 100,000 years (Mitchell, J. M., 1976; Shackleton and Opdyke, 1973; Berggren and others, 1980). Changes from glacial to interglacial intervals, and back again, are quasi-periodic. These changes are caused by variations in net global solar-energy input, a consequence of the precession of Earth's orbit and the obliquity and eccentricity of its axial position (Imbrie and Imbrie, 1980, p. 943-944; Sergin, 1980, p. 1480). Based on these findings, computer-simulated climatic models have been devised that indicate a significant probability that a new ice age will begin within the next 10,000 years (Imbrie and Imbrie, 1980, p. 949-951). The present Holocene Epoch is the last in a long series of relatively brief (7,000 to 20,000 years) interglaciations punctuating much longer (70,000 to 90,000 years) glaciations (Wright, 1972, p. 279-281; Broecker and Van Donk, 1970, fig. 2; Berggren and others, 1980, fig. 11). Hence, a permanent repository for nuclear waste must withstand the effects of a major climatic change that may occur well within the hazardous duration of these materials.

Objectives of Study

A site in or near the Nevada Test Site in south-central Nevada (fig. 1) is being evaluated as a permanent repository for both transuranic-contaminated and high-level radioactive wastes. The objective of this study is to characterize long-term climatic variability inherent to this area. Specifically, paleoenvironmental and paleoclimatic reconstructions spanning the last 45,000 years are offered to facilitate calculations of potential variations in water-table levels and ground-water recharge (Winograd, 1981, p. 1461; Winograd and Doty, 1980, p. 76-85). Radiocarbon-dated plant macrofossil assemblages from ancient packrat (*Neotoma* spp.) middens in the Nevada Test Site and vicinity provide data for these paleoclimatic reconstructions. The uniformitarian assumption is made that climates of the last 45,000 years approximate the climates that will occur in the next 100,000 years.



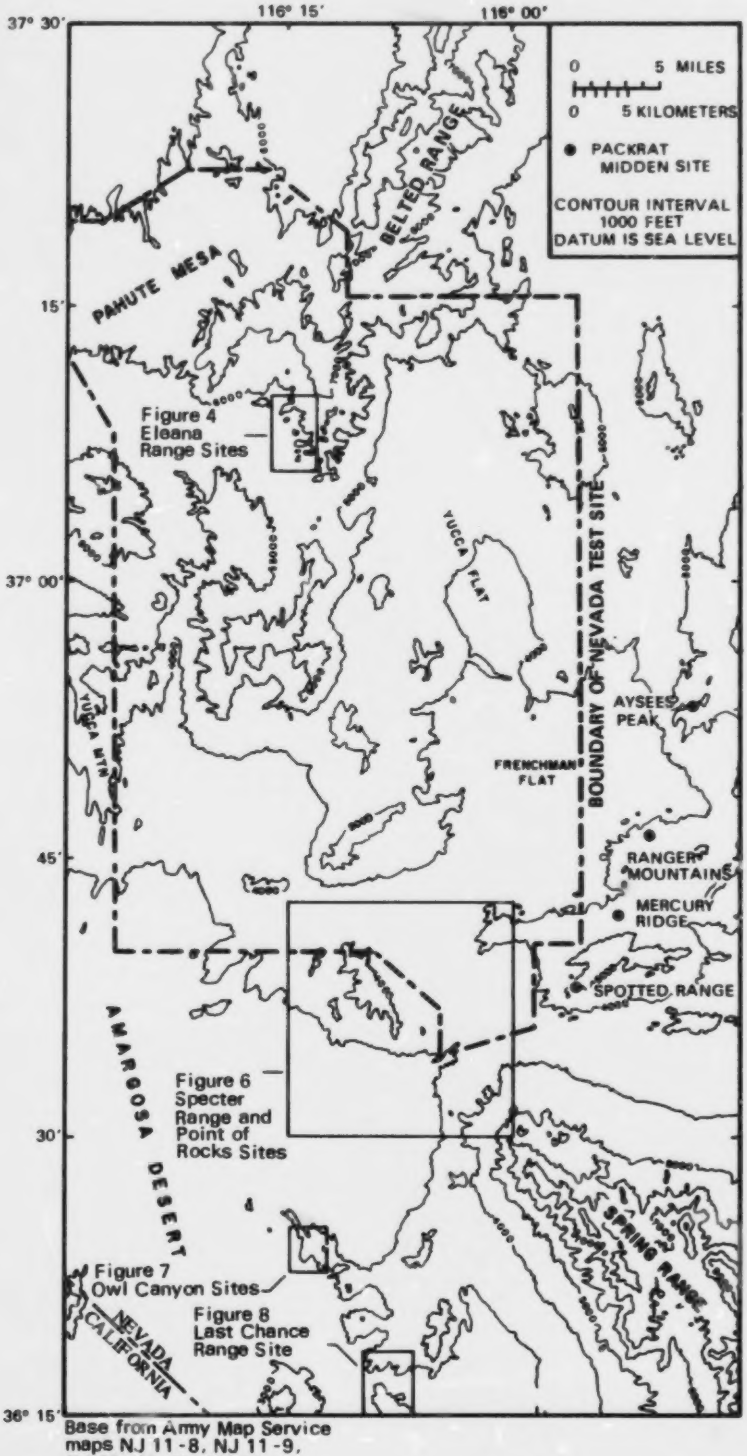
Base data from Defense Mapping Agency
Operational Navigation Chart G-18

Figure 1.--Location of study area, the Nevada Test Site and vicinity, and locations of figures 2, 12, and 13, and other selected sites.

Location of the Study Area

The Nevada Test Site lies within the Basin and Range Province of western North America (Fenneman, 1931), on the southeastern margin of the physiographic Great Basin (Snyder and others, 1964; Morrison, 1965) (fig. 1). With respect to flora, the site is located on the boundary of the Mojave Desert to the south and the Great Basin Desert to the north (Cronquist and others, 1972, figs. 55 and 56). Topography consists of desert valleys with relatively high floors (exceeding 700 m) surrounded by mountains with maximum elevations usually less than 2,100 m. Highlands of Tertiary volcanic rocks occupy much of the northern one-half of the site; while, in the south, uplands of Paleozoic carbonate rocks surround alluviated valleys. Two internally drained valleys, Yucca Flat and Frenchman Flat, are near the western boundary of the test site (fig. 2); playa elevation of Yucca Flat is 1,195 m, and playa elevation of Frenchman Flat is 939 m. Like most valleys in southern Nevada, neither shows evidence of having contained "pluvial" lakes of Wisconsin age (Mifflin and Wheat, 1979, p. 15).

Some ground-water flow through the Nevada Test Site originates in volcanic highlands to the north, Pahute Mesa, Timber Mountain, and Yucca Mountain. The remainder enters the site from the east as underflow within the regional lower carbonate aquifer (Winograd and Thordarson, 1975, pl. 1; Winograd and Doty, 1980, fig. 1). Flow directions beneath the eastern part of the site are south and west from the highlands to springs at Ash Meadows in the Amargosa Desert. Ash Meadows is the site of an extensive network of springs; evidence exists for somewhat greater spring activity during the Wisconsin glacial age. Fossil tufa deposits occur as high as 40 m above present ground-water level in this area (Winograd and Doty, 1980, p. 48).



Base from Army Map Service maps NJ 11-8, NJ 11-9, NJ 11-11, NJ 11-12.

Figure 2.--Location of Nevada Test Site and figures 4, 6, 7, and 8 (see fig. 1 for the relative position of this map). Dots and numbers refer to packrat-midden sites discussed by Wells and Jorgensen (1964).

Regional Climate

South-central Nevada is arid to semiarid; dry air masses dominate upper air flow about 70 percent of the year. Continental polar (cool and dry) and continental tropical (warm and dry) masses are the most common. Moist maritime air (both tropical and polar) occurs with a frequency of only about 28 percent. Outbreaks of very cold and dry arctic air occur during the winter; however, these account for less than 5 percent of the air-mass type dominance through the year (Houghton and others, 1975). The study area is typified by an arid to semiarid climate, and, because evidence exists for increased effective moisture during late Quaternary time, climatic phenomena that cause precipitation in this area are of particular interest. The Nevada Test Site receives moisture as a consequence of two basic storm types: (1) Those resulting from winter cyclonic activity; and (2) those caused by intense summer convection.

During the cold season (late autumn through early spring), southward migration of the subtropical high-pressure zone brings mid-latitude depressions to the southwestern United States. Winter precipitation results from either frontal-cyclonic (Pacific-type storms) or non-frontal cyclonic circulation (Great Basin lows) (Houghton and others, 1975, p. 14; Bell, 1979, p. 376). In both instances, the Sierra Nevada to the west (fig. 1) is a major barrier to moist air moving inland from the Pacific. Pacific-type storms are caused by fronts trailing southward from eastward moving low-pressure cells. These lows are imbedded in prevailing westerlies; their normal track is inland from the Pacific Northwest into Canada, north of the study area (Bryson and Hare, 1974, fig. 26). However, a semipermanent low-pressure trough sometimes develops over the western United States and diverts Pacific-type storms far enough south to affect the study area (Sellers and Hill, 1974, p. 16). Southern Nevada usually is south of the low-pressure center, and maritime air contributing to resultant precipitation comes from the southwest. These winds skirt the southern edge of the Sierra Nevada that lies to the west of the study area (fig. 1), although the Transverse and Peninsular Ranges south of the Sierra Nevada create a substantial rainshadow. Maximum rain and snowfall from this type of disturbance usually occurs in western and northern Nevada (Houghton and others, 1975, p. 15).

In contrast to Pacific-type storms, Great Basin lows are non-frontal cyclonic disturbances; they are the chief source of winter precipitation in central and eastern Nevada. This type of "cut-off low" develops near the extremity of a front moving inland from the Pacific and is caused by strong thermal contrast between cold air behind the front and warmer air ahead of the disturbance (Houghton and others, 1975, p. 16; Bell, 1979, p. 377). Great Basin lows may remain stationary over Nevada for a few days, but eventually move eastward under the influence of prevailing westerlies. Moisture-bearing winds are drawn into the area from the northwest. Although they occur less often than Pacific-type storms, Great Basin lows are important sources of winter precipitation, because the low is centered over the region and may remain for several days. Great Basin lows are most common from April to June; Pacific-type storms are more frequent between October and April (Houghton and others, 1975).

When the subtropical high-pressure belt shifts northward during the summer, the study area is removed from the effect of mid-latitude depressions. Summer precipitation is rarely the product of large-scale frontal activity; instead, it occurs as localized thunderstorms that are caused by intense vertical air currents over heated terrain. Such convection commonly is combined with orographic uplift and convergence over mountains to produce moisture-laden thunderheads (Bell, 1979, p. 381; Sellers and Hill, 1974, p. 10). At the Nevada Test Site, about 25 percent of the annual precipitation falls during the summer (June through early September, Beatley, 1976, p. 21), a small proportion compared to values greater than 50 percent for summer rainfall in the Sonoran and Chihuahuan Deserts to the southeast (Bryson and Lowry, 1955; Hales, 1974). In these southern deserts, the summer rainfall usually lasts from mid-July through early September, and results from maritime air carried inland from the Gulf of Mexico (Hales, 1974, p. 331; Bryson and Lowry, 1955, p. 339). This high-level (above 70 kPa) flow is circulation on the western edge of the subtropical anticyclone commonly called the Bermuda High. However, southern Nevada is beyond the western limit of these northwest winds (Mitchell, V. L., 1976, fig. 3; Hales, 1974, p. 334). Analyses indicate a negligible contribution of moisture from the Gulf of Mexico during the summer in western Arizona, adjacent Nevada, and California. Instead, surface low pressure that develops over heated desert terrain generates advective flow of maritime air northward from the Gulf of California and the Pacific Ocean (Hales, 1974, p. 341; Huning, 1978, p. 79). In the late summer (mid-July through mid-September), most of the precipitable water aloft in the Mojave Desert appears to originate from low-level northern flow, rather than from upper-level northeasterlies originating over the Gulf of Mexico.

Tropical storms of August through October produce a different kind of warm-season precipitation event. These low-pressure disturbances originate in the south and account for at least 25 percent of annual rainfall in the southern California deserts (Court, 1974, p. 212). Resultant precipitation patterns differ from those produced by summer thunderstorms; tropical storms are intense cyclonic disturbances (such as hurricane Kathleen of 1976) that affect large areas. However, the majority of rain from these storms is restricted to area south of latitude 36° north (Huning, 1978, p. 83).

Plant Communities

Adequate reconstruction of paleoenvironments of the Nevada Test Site is in part dependent on understanding the taxonomy, ecology, and biogeography of the plant species currently in the area. Many of these were also part of the Wisconsin-age vegetation, and changes in their distribution and associations provide important clues to the climatic history of the region. Diverse topography, geology, and local climates of the Nevada Test Site combine to create a complex mosaic of plant associations. Vegetation ranges from sparse desertscrub (in the sense of Brown and others, 1979) in the lowest valleys, to well-developed woodland on highlands at elevations above 2,000 m. Only shear cliffs and playa floors are devoid of plants. Even seemingly barren Paleozoic carbonate hills of the Amargosa Desert support diverse communities of widely spaced shrubs and succulents of short stature.

The botanical nomenclature used in this report follows Beatley (1976) in most instances, with exceptions after Munz (1974), Cronquist and others (1972), and Holmgren and Reveal (1966). Vegetation analyses focus on plant communities of rocky slopes near fossil packrat-midden sites. These are areas of relatively heterogeneous vegetation, where rough topography presents a variety of microhabitats for different plant species. Vegetation of such areas is not well-known because plant ecologists usually prefer study sites of uniform topography supporting homogeneous vegetation for their purposes (Langford and Buell, 1968, p. 97; Mueller-Dombois and Ellenberg, 1974, p. 46-48). So, although principal plant-community types recognized in this study (table 1) have direct analogs in Beatley's (1976, p. 27-72) treatment of the vegetation of the Nevada Test Site, some representative plant associations do not. Plants, such as matchweed (*Gutierrezia microcephala*) and Mojave pepperweed (*Lepidium fremontii*), are common dominants on rocky slopes. In contrast, some plant species that typify associations on alluvial fans, such as blackbrush (*Coleogyne ramosissima*) and desert-thorn (*Menodora spinescens*), are less abundant on rocky slopes. Vegetation classification presented in table 1 also differs from Beatley's (1976, p. 27-72), in that "transition desert" is not recognized as a plant-community type. Plant associations included in the "transition desert" by Beatley (1976, p. 41-52), such as those dominated by *Coleogyne*, *Larrea-Grayia-Lycium*, and *Lycium-Grayia*, are considered in table 1 to be representatives of Mojave desertscrub (Brown and others, 1979, p. 10).

Table 1.--*Principal plant-community types and examples of representative plant associations on rock slopes*

[Classification system follows that of Brown and others (1979)]

Representative plant associations	Distribution and common associates
GREAT BASIN CONIFER WOODLAND	
Pinus monophylla-*Quercus gambelii*-*Juniperus osteosperma*	Volcanic highlands in the northern test site; generally at elevations above 1,950 meters (such as the eastern Pahute Mesa, Timber Mountain). Associates include *Artemisia tridentata*, *Symphoricarpos longiflorus*, *Purshia tridentata*, and *Lupinus argenteus*.
Pinus monophylla-*Artemisia tridentata*-*Juniperus osteosperma*	Highlands at elevations above 1,770 meters; restricted to xeric habitats at elevations above 2,100 meters. Common associates include *Artemisia nova*, *Cowania mexicana*, *Haplopappus nanus*, *Brickellia microphylla*.
GREAT BASIN DESERTSCRUB	
Atriplex canescens-mixed scrub	The flanks of hills and rocky mesas, usually of volcanic substrate; at elevations from about 1,500 to 2,000 meters. Common associates are usually Great Basin desertscrub species such as *Chrysothamnus nauseosus*, *C. viscidiflorus*, *Ephedra viridis*, *Tetradymia canescens*, *Artemisia nova*.
Atriplex confertifolia-mixed scrub	On limestone and dolomite slopes; at elevations from about 850 to 1,700 meters. Common associates are usually Mojave Desert shrubs such as *Amphipappus fremontii*, *Ephedra torreyana*, *Larrea divaricata*, *Gutierrezia microcephala*.

Table 1.--*Principal plant-community types and examples of representative plant associations on rock slopes*--Continued

Representative plant associations	Distribution and common associates
MOJAVE DESERTSCRUB	
Lepidium fremontii-mixed scrub	On the talus slopes and ridges of calcareous mountains; at elevations from about 1,050 to 1,700 meters. Associates include a diverse complement of upper elevation Mojave desertscrub species such as *Coleogyne ramosissima*, *Ephedra torreyana*, *Buddleja utahensis*, and *Lycium andersonii*.
Gutierrezia microcephala-mixed scrub	Talus slopes, cliff bases, and ridges; generally at elevations below 1,400 meters on calcareous substrates. Common associates include *Larrea divaricata*, *Ambrosia dumosa*, *Ephedra* spp., *Amphipappus fremontii*, *Lycium pallidum*.
Ambrosia dumosa-*Larrea divaricata*	On talus slopes, ridges, and mesas; generally at elevations below 1,200 meters. Normally occurring with lower-elevation Mojave Desert species such as *Peucephyllum schottii*, *Eucnide urens*, *Gutierrezia microcephala*, *Echinocactus polycephalus*. *Atriplex confertifolia* is common at some sites.

Plant associations classified as Great Basin conifer woodland are distinguished by dominance of single-needle pinyon pine (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*). In south-central Nevada, these pygmy conifer communities are restricted to elevations above 1,800 m. Dominant plant taxa in Great Basin desertscrub communities are those with northern floristic affinities, such as shadscale (*Atriplex confertifolia*) (Billings, 1949). These desertscrub associations usually occur below woodland, but above Mojave Desert vegetation. The plant species typical of lower elevation Mojave desertscrub vegetation, like creosote bush (*Larrea divaricata*) and white bursage (*Ambrosia dumosa*), have their center of distribution south of the Nevada Test Site. Exceptions include plant associations dominated by species endemic to the northern Mojave Desert, such as Shockley's boxthorn (*Lycium shockleyi*) and Bailey's greasewood (*Sarcobatus vermiculatus* var. *baileyi*). Many Mojave desertscrub species are at the northern limits of their distribution in the vicinity of the Nevada Test Site, and most are restricted to elevations below 1,800 m.

Acknowledgments

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PACKRAT-MIDDEN ANALYSIS

Comprehensive paleoenvironmental reconstruction depends on a reliable source of fossils. In temperate regions, our knowledge of late Quaternary climates is based primarily on organic remains preserved in lakes and bogs. However, sedimentary basins in arid regions usually do not provide well-preserved fossil remains, and other sources of information are required. In the early 1960's, a new paleoecological tool was introduced, analysis of packrat middens or paleonidology (Wells and Jorgensen, 1964; Wells, 1976; Spaulding, 1977, p. 3), and its use has provided novel insights into the late Quaternary environments of western North America. Paleonidology is the reconstruction of past vegetation from plant remains preserved in middens deposited in rock cavities by cricetid rodents of the genus Neotoma (packrats, woodrats, trade-rats, or go-atters).

All species of Neotoma share an acquisitive behavioral trait and construct houses or dens from plant debris collected nearby (Finley, 1958; Wells, 1976). Functionally specific areas within a packrat den include nest chambers, food caches, and trash middens (Van Devender, 1973, p. 7-9). Plant debris from trash middens are the focus of this study. Middens contain primarily fecal pellets and plant remains in the form of shredded fibers, twigs, seeds, leaves, and flowers. Currently active middens are loose debris piles, while ancient middens are usually masses solidified by dehydrated urine. Middens often serve as urination points, and cementation is caused by saturation with urine which, upon drying, encases the refuse in a cohesive, crystalline mass. Crystallized packrat urine, called amberat, is hygroscopic and rehydrates during infrequent periods of high humidity. Capillary action draws rehydrated amberat to any fresh break on an indurated midden, where it then will dry and recrystallize. Within a few months, new breaks on ancient middens are sealed by a shiny layer of recently active amberat. Such surfaces are sticky whenever it is humid; in time, they incorporate dust and debris to become lusterless rinds that are no longer subject to rehydration. Hence, indurated packrat middens are self-sealing, with typically convoluted rinds that vary in thickness from a few millimeters to several centimeters; (see figs. 3 and 4 for views of the Eleana Range-2 middens).

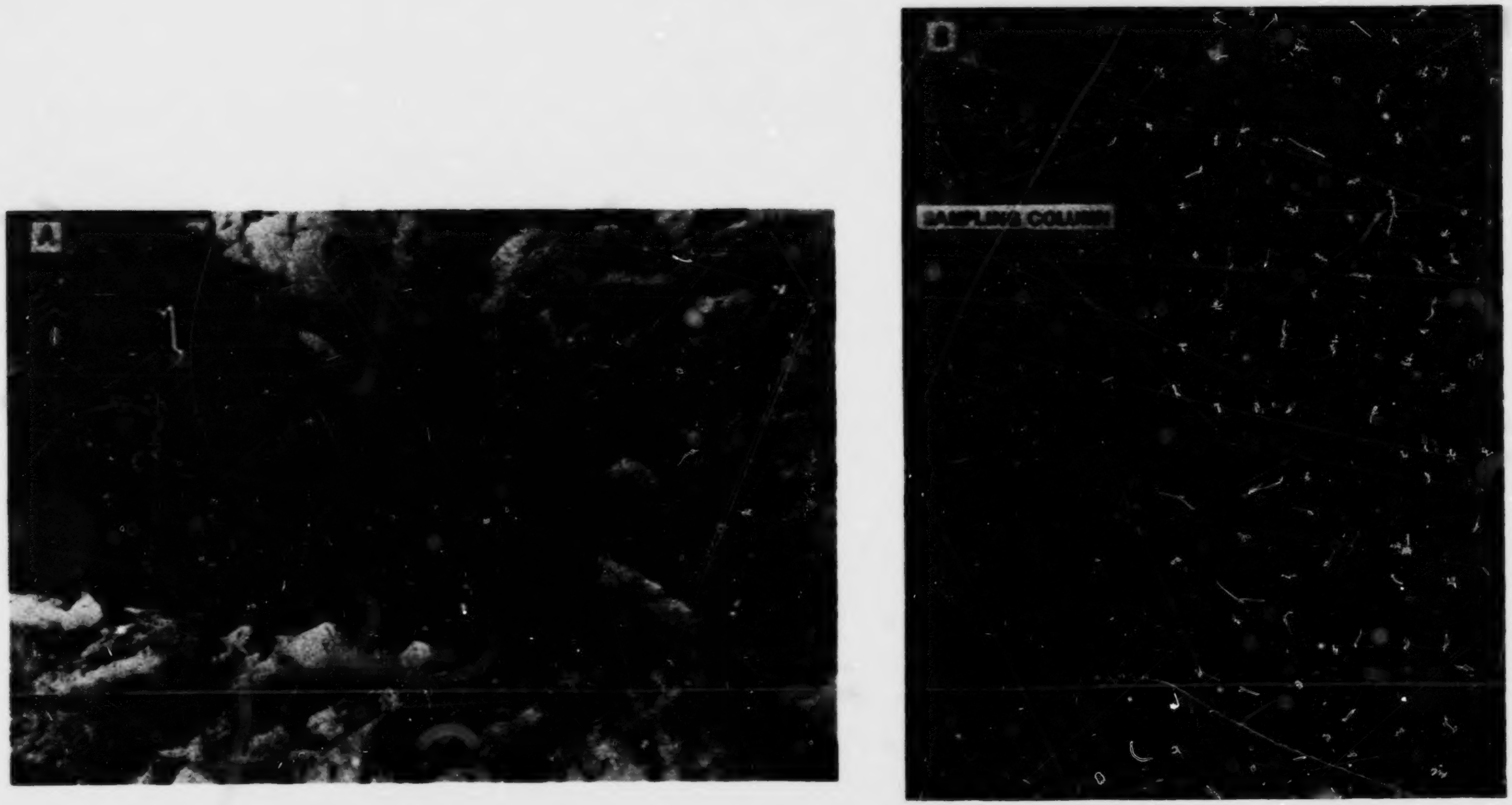
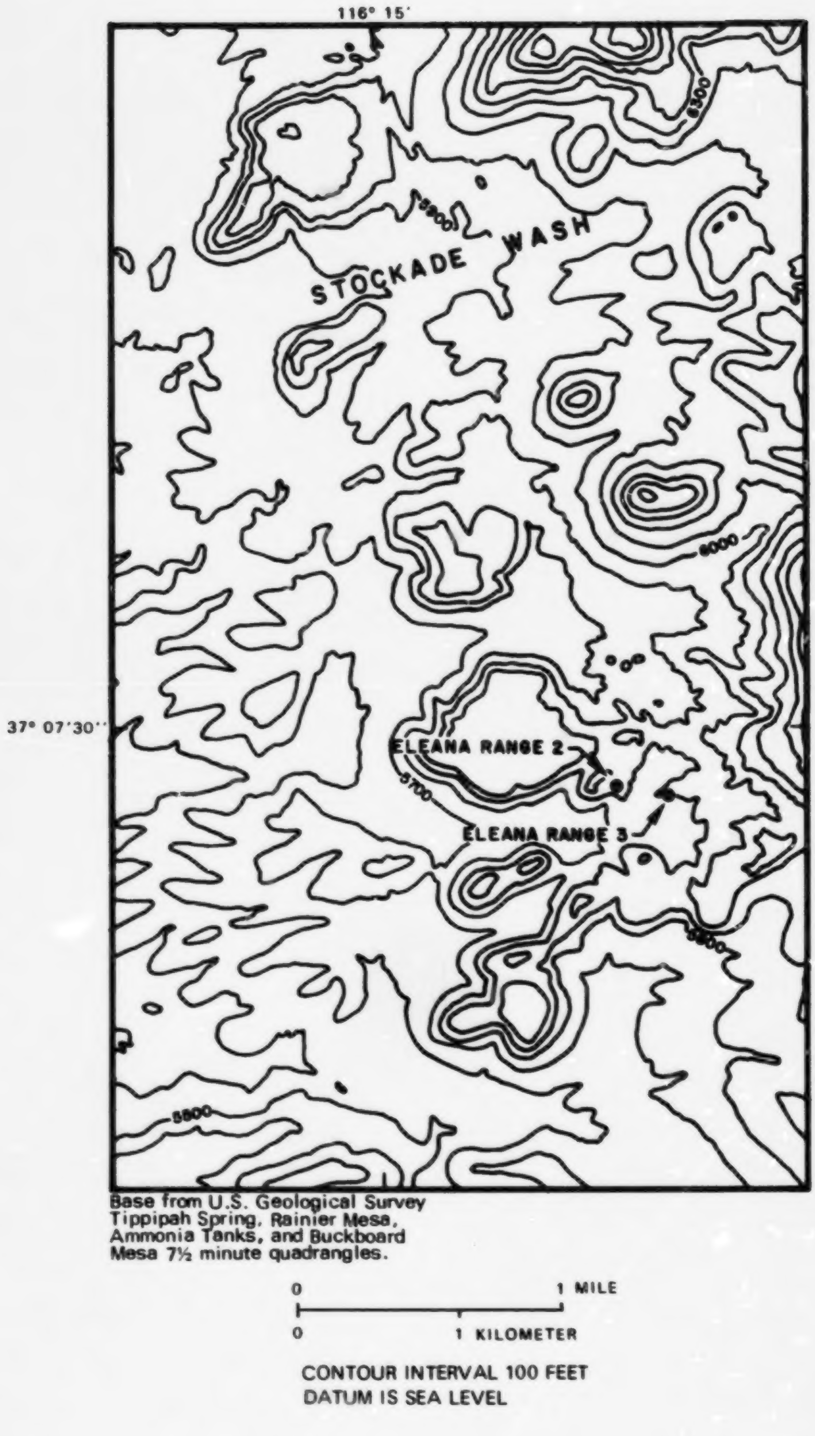


Figure 3.--The Eleana Range-2 packrat midden: A. General view of the external face of the midden; the rod at the top left of the midden is graduated in inches; B. Closeup view of the sampling column after removal of the weathering rind; nails at 10-centimeter intervals; see figure 4 for the location of the Eleana Range-2 midden site.



Base from U.S. Geological Survey
Tippipah Spring, Rainier Mesa,
Ammonia Tanks, and Buckboard
Mesa 7½ minute quadrangles.

CONTOUR INTERVAL 100 FEET
DATUM IS SEA LEVEL

Figure 4.--Eleana Range fossil locality. (See fig. 2 for the relative position of this map.)

Although the properties of amberat augment longevity of indurated middens, mummification is the prime means of preservation. Middens must be sheltered from rain in a cave or beneath a rock overhang to be preserved. Decomposition is rare in well-sheltered middens. Middens from exposed sites are degraded and of a "punky" consistency, with most of the amberat leached out by repeated wetting. Extensive termite damage is common in such samples. However, given adequate shelter, plant fossils from middens remain well preserved. Some are more than 50,000 years old and are among the oldest fossils preserved by mummification.

In most instances, 80 to 95 percent of the mass of an indurated packrat midden is soluble urine and particles less than 0.85 mm in size (table 2). Most of the remaining 5 to 20 percent is composed of fecal pellets and plant debris. Identifiable plant remains normally comprise much less than 10 percent of the mass of an indurated midden, although they commonly number into the thousands per kilogram of unprocessed midden.

Methods

Paleonidology is a new scientific discipline with few established guidelines and few standardized methods. The first time series of macrofossil assemblages from single localities only were described in 1980 and 1981 (Spaulding, 1980; Betancourt and Van Devender, 1981; Mead and Phillips, 1981). Therefore, a secondary objective of this study is to develop techniques that increase the resolution of inferences drawn from midden analysis and to test some assumptions of the discipline.

Table 2.--*Dry weight and percentage composition of different size fractions of packrat-midden samples after dissolution and washing*

[Wtw, sum of weight of the >3.35-millimeter and 3.35>0.85-millimeter fractions; Wti, initial weight of sample; ER, Eleana Range; Spc, Specter Range: PR, Point of Rocks; OC, Owl Canyon; LCR, Last Chance Range]

Site and sample no.	Initial weight (grams)	Weight of recovered material (grams) for the indicated size fractions (millimeters) below				$\frac{Wtw}{Wti} \times 100$ (percent)
		>3.35	3.35>0.85	[1]<0.85	Wtw	
ER-2(1)	437	18.6	25.5	4.2	44.1	10.1
ER-2(2)	501	32.1	26.1	6.1	58.2	11.6
ER-2(3)	460	53.2	22.5	5.7	75.7	16.5
ER-2(4)	778	35.2	36.7	8.8	71.9	9.2
ER-2(5)	903	37.8	28.8	4.4	66.6	7.4
ER-2(6)	1,545	92.2	108.3	22.7	200.5	13.0
ER-2(7)	798	64.1	45.8	11.0	109.9	13.8
ER-2(9)	1,155	58.5	54.6	15.1	113.1	9.8
ER-2(10)	1,826	58.4	112.1	41.3	170.5	9.3
ER-2(11)	937	18.7	48.8	14.7	67.5	7.2

Table 2.--*Dry weight and percentage composition of different size fractions of packrat-midden samples after dissolution and washing*--Continued

Site and sample no.	Initial weight (grams)	Weight of recovered material (grams) for the indicated size fractions (millimeters) below				$\frac{Wtw}{Wti}$ x 100 (percent)
		>3.35	3.35>0.85	1/<0.85	Wtw	
ER-3(2)	937	74.9	32.7	17.3	107.6	11.5
ER-3(3)	667	54.1	43.0	21.2	97.1	14.6
ER-3(4)	1,498	165.1	71.5	38.5	236.6	15.8
ER-3(6)	1,430	77.0	49.2	20.3	126.2	8.8
ER-3(7)	1,327	120.5	71.0	27.0	191.5	14.4
ER-3(8)$_2$	1,270	89.0	58.2	30.6	147.2	11.6
ER-3(8)$_3$	2,522	221.5	112.1	75.7	333.6	13.2
ER-3(9)	615	46.2	36.0	20.2	82.2	13.4
ER-3(10)	689	27.2	35.6	16.6	62.8	9.1
Spc-1(1)	635	110.0	47.0	10.0	157.0	24.7
Spc-1(2)	524	161.0	48.0	9.0	209.0	39.9

Table 2.--*Dry weight and percentage composition of different size fractions of packrat-midden samples after dissolution and washing*--Continued

Site and sample no.	Initial weight (grams)	Weight of recovered material (grams) for the indicated size fractions (millimeters) below				$\frac{Wtw}{Wti} \times 100$ (percent)
		>3.35	3.35>0.85	[1]<0.85	Wtw	
Spc-2(2)$_1$	374	29.8	28.0	7.1	57.8	15.5
Spc-2(2)$_2$	994	104.0	60.0	11.0	164.0	16.5
Spc-2(3)	991	38.8	57.4	15.4	96.2	9.7
Spc-2(6)	758	14.4	16.6	17.2	61.0	8.0
Spc-2(8)	513	34.5	26.3	12.2	60.8	11.9
Spc-2(10)	206	6.6	12.9	5.2	19.5	9.5
Spc-2(11)$_1$	289	55.0	32.0	4.0	87.0	30.1
Spc-2(11)$_2$	933	71.0	13.0	13.0	151.0	16.2
Spc-2(12)	934	22.0	47.1	13.9	69.1	7.4
Spc-3A(1)	1,171	21.9	53.9	10.6	75.8	6.5
Spc-3A(2)	808	26.7	51.6	13.8	78.3	9.7
Spc-3B	567	11.2	30.9	7.5	42.1	7.4

Table 2.--*Dry weight and percentage composition of different size fractions of packrat-midden samples after dissolution and washing*--Continued

Site and sample no.	Initial weight (grams)	Weight of recovered material (grams) for the indicated size fractions (millimeters) below				$\frac{Wtw}{Wti} \times 100$ (percent)
		>3.35	3.35>0.85	[1]<0.85	Wtw	
PR-1(1)	880	26.2	30.1	12.1	56.3	6.4
PR-1(3)	629	41.5	27.3	12.4	68.8	10.9
PR-2(2)	699	23.6	22.6	9.2	46.2	6.6
PR-2(3)	1,000	70.9	40.1	17.7	111.0	11.1
PR-3	712	9.3	50.1	21.4	59.4	8.3
OC-2(1)	345	15.0	22.9	10.6	37.9	11.0
OC-2(3)	588	36.2	37.2	12.5	73.4	12.5
OC-3(1)	755	6.9	17.5	4.2	24.4	3.2
OC-3(2)	730	20.0	18.1	7.1	38.1	5.2
LCR-1(2)	382	8.9	12.0	3.6	20.9	5.5
LCR-1(3)	462	17.6	28.0	12.7	45.6	9.9

[1] Dry sieve only.

Sampling

Packrat middens occur in a great variety of sizes, shapes, and situations within a rock cavity. Guidelines for site and sample selection were devised to minimize the chances of collecting contaminated samples (those containing plant fossils of more than one radiocarbon age). Deposits in vertical fissures were not collected, because different-age debris falling from above may be incorporated into a midden. Middens displaying jumbled stratigraphy were rejected, including most of those that were not well-consolidated. Using these criteria, about one-half the indurated middens located were collected, and about two-thirds of those were chosen for detailed analysis.

Most indurated *Neotoma* middens are less than 0.5 m^3 in volume and provide samples from only a narrow span of radiocarbon time. However, larger deposits do exist; the volume of some exceed 4 m^3. A series of macrofossil assemblages from such a large deposit may span more than 10,000 years and is more useful for paleoclimatic reconstruction than one or two samples from many isolated sites. Hence, priority was given to locating and collecting those rare, large middens.

A midden judged suitable for analysis is first sketched and photographed. A vertical section of weathering rind is then removed; the exposed stratigraphy is sketched, and the position of samples to be taken is noted. A variety of chisels, wedges, and pry-bars are used to remove discrete blocks from the indurated mass. Ancient middens characteristically contain many minor laminae; major stratigraphic boundaries usually are marked by interbedded weathering rinds. Midden sampling is facilitated by their tendency to split along the bedding planes defined by laminae. After removal, samples are placed in plastic bags. These bags are then wrapped tightly with masking tape (to avoid fracturing during transport) and labelled.

All plant species within 30 m of a midden site are inventoried. Supplemental data are taken on other trees, shrubs, and succulents, and plant-community types, within 0.5 km of the site. Woody plants growing within 30 m were subjectively assigned the following abundance classes according to their importance in the local vegetation: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare. Most grasses and forbs are designated by an "X" in the modern plant lists, indicating their occurrence within 30 m of the midden sites.

Analysis

In the laboratory, each midden sample is examined for stratification, and, if necessary, split into subsamples for analysis. Samples are cleaned, weighed, rinsed under running water, and then immersed in warm water. Smaller subsamples usually are saved for pollen analysis. Immersion for 2 to 4 days is usually sufficient to dissolve the amberat in most indurated samples, releasing the plant macrofossils. Upon disaggregation, the mass is washed through a nested pair of No. 6 (3.35-mm mesh) and No. 20 (0.85-mm mesh) 12-inch (30.5-cm) Tyler* soil sieves. Material captured on the sieves is flushed with warm water, knocked onto paper blotters, and then dried in a forced-air oven at 50°C for 6 to 12 hours. The dried debris then is stored in labelled plastic bags. Prior to sorting, the debris is dry sieved through Nos. 6 and 20 screens to disaggregate fibrous clots that develop on the screens during wet-sieving and to remove remaining fine chaff. The different size fractions are then weighed (table 2).

Identifiable plant fragments and faunal remains are handsorted and placed in labelled plastic vials. Identifications are made by comparing the fossils with modern reference specimens under a stereo-dissecting microscope. Certain biases are incorporated into identification of this fragmentary plant material. Grasses and composites (Poaceae and Asteraceae) are frequently difficult to identify under these circumstances (Van Devender, 1973, p. 16-17; Spaulding, 1981, p. 76-79). Those that could not be identified to genus were grouped into the categories "Poaceae undetermined" or "Asteraceae undetermined." Similarly, fossils of plant genera with morphologically similar species were often difficult to identify to the species level. Hence, such fossil taxa as "_Artemisia_ sec. Tridentatae,' "_Ephedra_ sp.," and "_Eriogonum_ sp."

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*Use of trade and firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Traditionally, subjectively assigned relative values have been used to describe the abundance of taxa in a midden assemblage (for example, Wells and Berger, 1967; Phillips, 1977; Spaulding, 1981). This method was not used; instead, the fossil data are reported in terms of the number of specimens counted in each midden sample (see Supplemental Data section). Relative abundance of a fossil taxon can be expressed as a percentage of the total number of identified specimens (NISP) counted in a sample (Grayson, 1979). One problem with this approach is the remains of a single arboreal taxon (AT) generally will be so abundant that they are impractical to count. In such instances, the total number of identified specimens minus the arboreal taxon (NISP-AT) still provides a useful parameter for calculating relative frequencies of all other fossil types. Relative importance of a superabundant fossil type can be expressed as a concentration value. Preliminary analyses indicate that a useful parameter is the ratio of the weight of the fossils of a superabundant species to the weight of the sorted midden sample (all identifiable macrofossils and fecal pellets removed).

In this study, NISP counted in single assemblages ranges from 192 to 2,674. A minimum number of 1,000 identified specimens was counted whenever possible. Variations in the number of identified plant taxa (N) in samples from the Specter Range-2 midden, as functions of sample weight after washing and NISP, are presented in figure 5. Point of Rocks and Specter Range fossil localities are shown in figure 6. It appears that samples weighing less than 70 g after washing (about 350 to 700 g initial weight, depending on amberat concentration) (table 2), or those with a NISP of less than 600, may provide underrepresentative estimates of N.

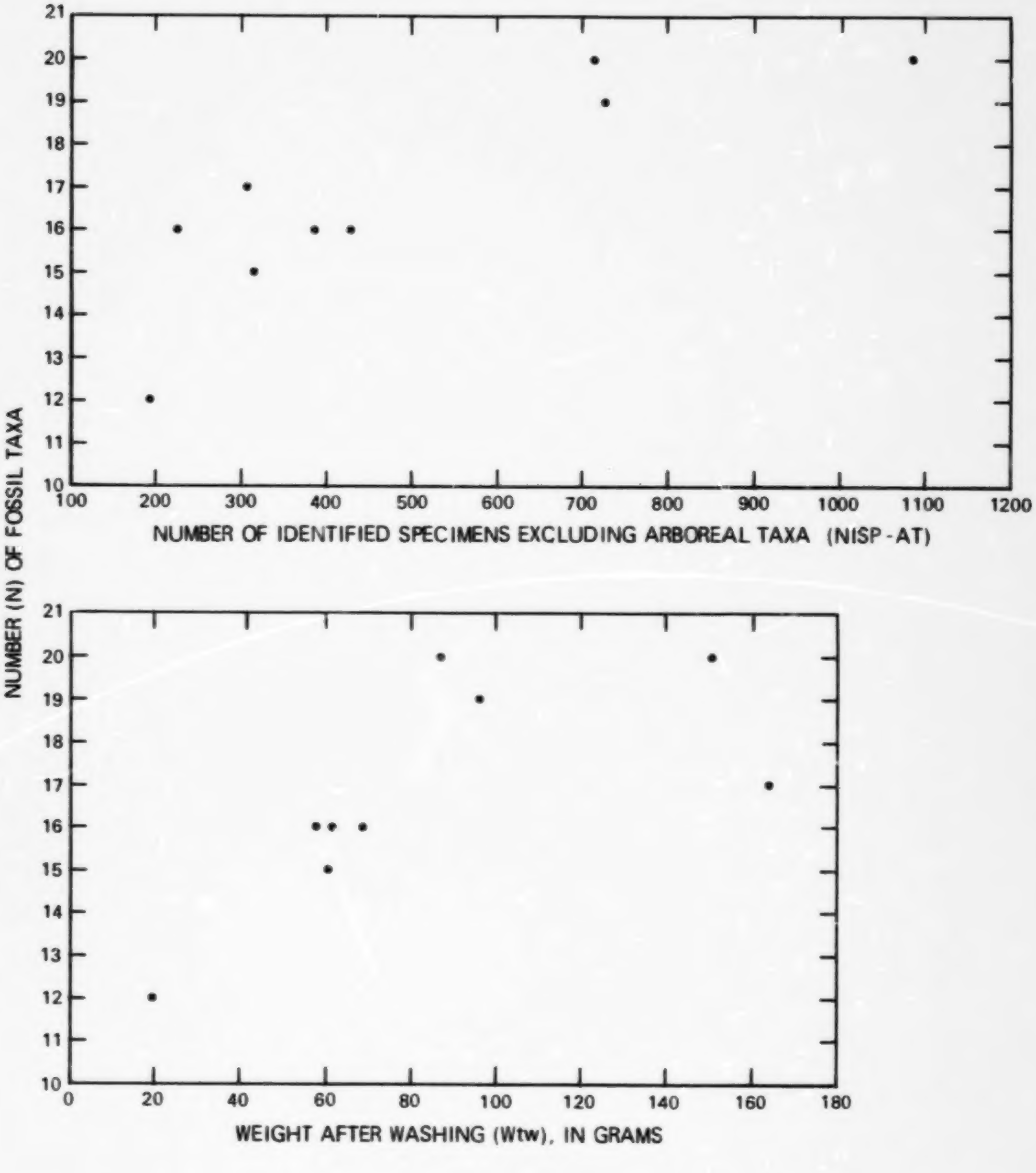
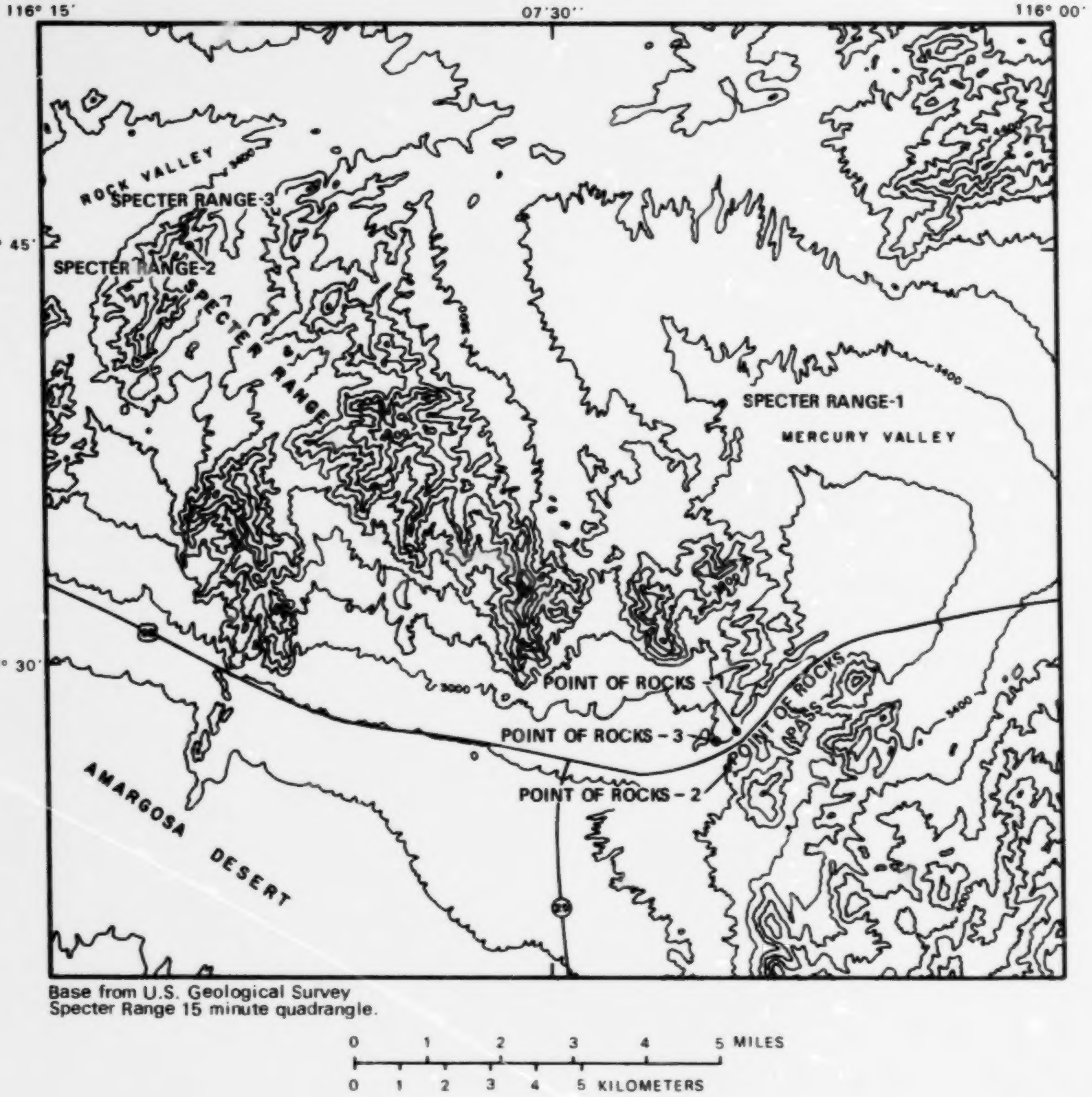


Figure 5.--Diversity as a function of the size of samples from the Specter Range-2 packrat midden (data are from table 2). See figure 6 for the location of the Specter Range-2 midden site.



Base from U.S. Geological Survey
Specter Range 15 minute quadrangle.

CONTOUR INTERVAL 200 FEET
DATUM IS SEA LEVEL

Figure 6.--Specter Range and Point of Rocks fossil localities (see figure 2 for the location of this map).

A widely used similarity coefficient proposed by Sorensen (1948) takes the form:

$$IS = \frac{2c}{A + B} \times 100$$

where

IS (similarity index) is a percentage of the total number of taxa in both samples, with possible values ranging from 0 (none in common) to 100 (all taxa shared);

c is the number of plant taxa common to two samples;

A is the number of taxa in one sample; and

B is the number of taxa in the other.

This formula gives weight to the species recurring in two assemblages (Mueller-Dombois and Ellenberg, 1974, p. 215) and, as a consequence, may be less sensitive to random variability in midden content. The total number of trees, shrubs, and succulents (N_{ts}) is used to compute IS, eliminating some of the bias created by the difficulty in identifying grasses and herbaceous species. If two samples have a taxon that is identified to genus in one and species in another (such as *Ephedra viridis* and *Ephedra* sp.), they are considered identical in computing IS.

Modern Analogs

Validity of these paleoecological reconstructions rests on the fidelity with which macrofossil assemblages reflect past vegetation. *Neotoma* forages only within a limited area around the den. Studies of different packrat species indicate that foraging distances seldom exceed 30 m and then only when brush or broken terrain provide cover (Bleich and Schwartz, 1975; Stones and Hayward, 1968; Cranford, 1977; Raun, 1966). Therefore, plant fossils from a packrat midden are autochthonous and represent only local paleovegetation.

Analysis of active packrat middens from different vegetation types addresses two interrelated questions: (1) How closely do relative proportions of plant fragments correspond to their relative abundance in the local community; and (2) how complete an inventory of local vegetation is the list of plant taxa from a midden? Modern middens were treated in the same manner as fossil samples. Approximately 1 kg of loose debris was collected from a midden in a currently active den. A subsample of about 500 g was soaked for a short time to simulate the disaggregation treatment used on indurated middens; then it was wet-sieved and dried. Dry-sieving, sorting, and identification followed. NISP in these modern samples ranged from 999 to 2,069 (see Supplemental Data section). Indices of similarity between local vegetation and modern midden assemblages ranged from 67 to 84. These compare favorably with an average IS of 77 for 6 assemblages less than 1,200 years old from the Grand Canyon (Cole, 1981, p. 38) and an IS of 77 for a single modern midden from the Sheep Range (Spaulding, 1981, p. 70). An additional two modern middens from the Connley Hills, outside the study area in southeastern Oregon (lat 43°16' N., long 121°04' W.), were analyzed because these sites occur in low-diversity vegetation. Indices of similarity for these samples were higher than those for middens from the study area, 91 and 100, presumably because of the low number of plant species at the sites.

Between 17 and 27 percent of the plant taxa noted in the modern middens from the Nevada Test Site and vicinity were not observed at the midden sites. Most of these are rare occurrences in the midden samples, usually represented by relative percentages (of NISP) of less than 1 percent. Of the plant species in the current vegetation within 30 m of the sites, between 16 and 32 percent (excluding the Connley Hills samples) were not found in the modern midden debris. Again, most of these species are rare at the site today; none are common or abundant.

An array of the common species in the modern plant associations and active packrat middens is presented in table 3. The Owl Canyon-3 (fig. 7), Last Chance Range-1 (fig. 8), and Specter Range-2 (fig. 6) sites support Mojave desertscrub vegetation. The Eleana Range-3 (fig. 4) and Connley Hills-1 sites are at transitions from Great Basin desertscrub to woodland; Connley Hills-2 is in an open juniper woodland. As mentioned previously, local vegetation of the Connley Hills sites is of low diversity (N_{ts}=5). Modern middens at this locality provide a contrast with those from sites supporting relatively diverse vegetation in southern Nevada (N_{ts}=14 to 19).

Differences occur between observed abundance of plant species in modern vegetation and their frequency in midden assemblage (table 3). Those species rated as common or abundant in modern vegetation (relative abundance values of 3 to 5) are not always common or abundant (relative frequencies $\geq$ 5 percent) in modern midden assemblages. Some shrubby Asteraceae appear underrepresented; however, there are exceptions, such as the abundance of Gutierrezia microcephala in the Owl Canyon-3 assemblage (table 3). Larrea divaricata appears overrepresented in the Owl Canyon-3 midden, as does Juniperus in both modern assemblages from the Connley Hills. However, Larrea appears proportionately represented in the Last Chance Range-1 assemblages, as does Juniperus in the Eleana Range-3 sample. The Connley Hills-1 midden is of particular interest. The nearest junipers are at the woodland border, about 28 m from the rock shelter containing the midden, and there are none in the Chrysothamnus-dominated association nearer the site. Nevertheless, juniper twigs and seeds comprise 27 percent of identified plant debris from the midden.

page 38 follows

Table 3.--*Comparison of key plant taxa*
in the vegetation within
[See tables 11-15 in Supplemental Data
species involved at each site; %, perce

	Current vegetation (relative abundance)		
Site	Abundant (4-5)	Common (3)	Occasional (2)
Owl Canyon-3	*Ambrosia dumosa* *Gutierrezia microcephala*	*Eucnide urens* *Peucephyllum schottii* *Pleurocoronis pluriseta*	*Echinocactus polycephalus*
Last Chance Range-1	*Ambrosia dumosa* *Larrea divaricata*	*Atriplex confertifolia* *Bromus rubens* *Buddleja utahensis* *Eucnide urens*	*Gutierrezia microcephala* *Nicotiana trigonophylla* *Stipa arida*
Specter Range-2	--	*Atriplex confertifolia* *Ephedra torreyana* *Eriogonum heermannii* *Gutierrezia microcephala* *Prunus fasciculata* *Scopulophila rixfordii* *Stipa arida*	*Brickellia watsonii* *Buddleja utahensis*
Eleana Range-3	*Atriplex canescens*	*Artemisia tridentata* *Stipa* sp. *Ephedra viridis*	*Artemisia nova* *Haplopappus nanus* *Pinus monophylla* *Symphoricarpos longiflorus* *Juniperus osteosperma*
Connley Hills-1	*Artemisia tridentata* *Chrysothamnus nauseosus*	Poaceae undet.	*Bromus tectorum*
Connley Hills-2	*Crysothamnus nauseosus*	*Artemisia tridentata* *Bromus tectorum* *Juniperus occidentalis*	Poaceae undet.

in modern packrat-midden debris with plants

30 meters of the midden site

section for a complete list of the plant

nt; NISP, number of identified specimens]

	Recent midden (percent of NISP)	
Abundant (>20 percent)	Common (5 ≤ 20 percent)	Occasional (2 ≤ 5 percent)
Larrea divaricata (37%) *Gutierrezia microcephala* (22%)	*Linanthus* sp. (8%) *Eucnide urens* (6%)	*Cryptantha* sp. (4%) *Peucephyllus schottii* (3%) *Ambrosia dumosa* (3%) *Aristida* sp. (2%)
Larrea divaricata (46%)	*Atriplex confertifolia* (12%) *Ambrosia dumosa* (8%) *Eucnide urens* (5%)	*Mortonia utahensis* (4%) *Ephedra* sp. (3%) *Buddleja utahensis* (3%) *Brickellia desertorum* (2%)
Atriplex confertifolia (42%) *Ephedra torreyana* (21%)	*Scopulophila rixfordii* (12%) *Prunus fasciculata* (8%)	*Buddleja utahensis* (2%) Poaceae undet. (2%)
Atriplex canescens (39%)	Poaceae undet. (18%) *Cowania mexicana* (15%) *Pinus monophylla* (8%) *Juniperus osteosperma* (7%)	*Oryzopsis hymenoides* (3%) *Artemisia* sec. Tridentatae
Poaceae undet. (56%) *Juniperus occidentalis* (27%)	*Chysothamnus* sp. (9%)	*Chrysothamnus nauseosus* (2%) *Bromus tectorum* (2%)
Juniperus occidentalis (58%)	*Chrysothamnus nauseosus* (13%) Poaceae undet. (9%) *Artemisia tridentata* (8%) *Desurainia* sp. (5%)	*Chenopodium* cf. *botrys* (3%) *Chrysothamnus* sp.

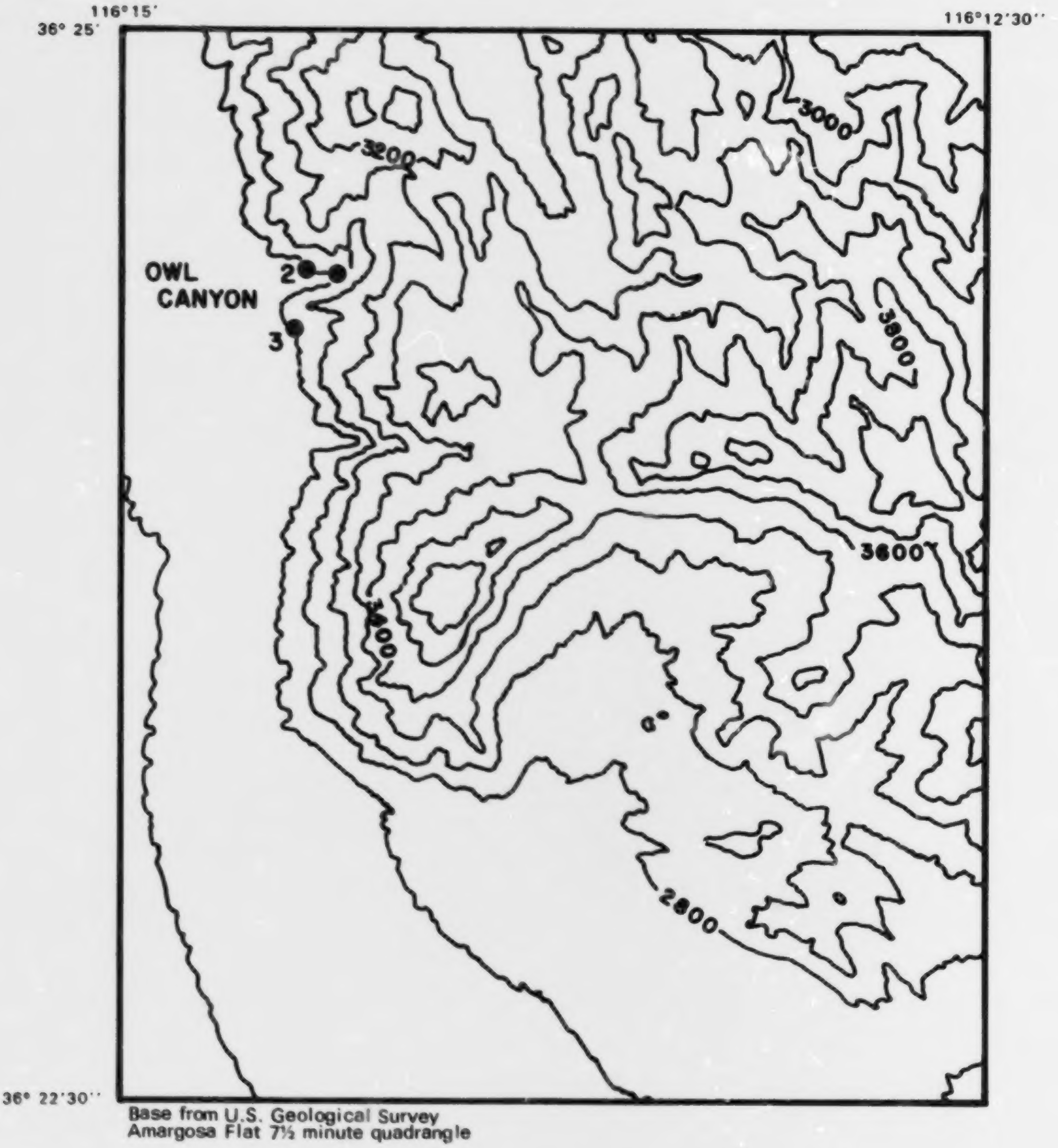


Figure 7.--Owl Canyon fossil locality. (See fig. 2 for the location of this map; position of the Owl Canyon site is approximate.)

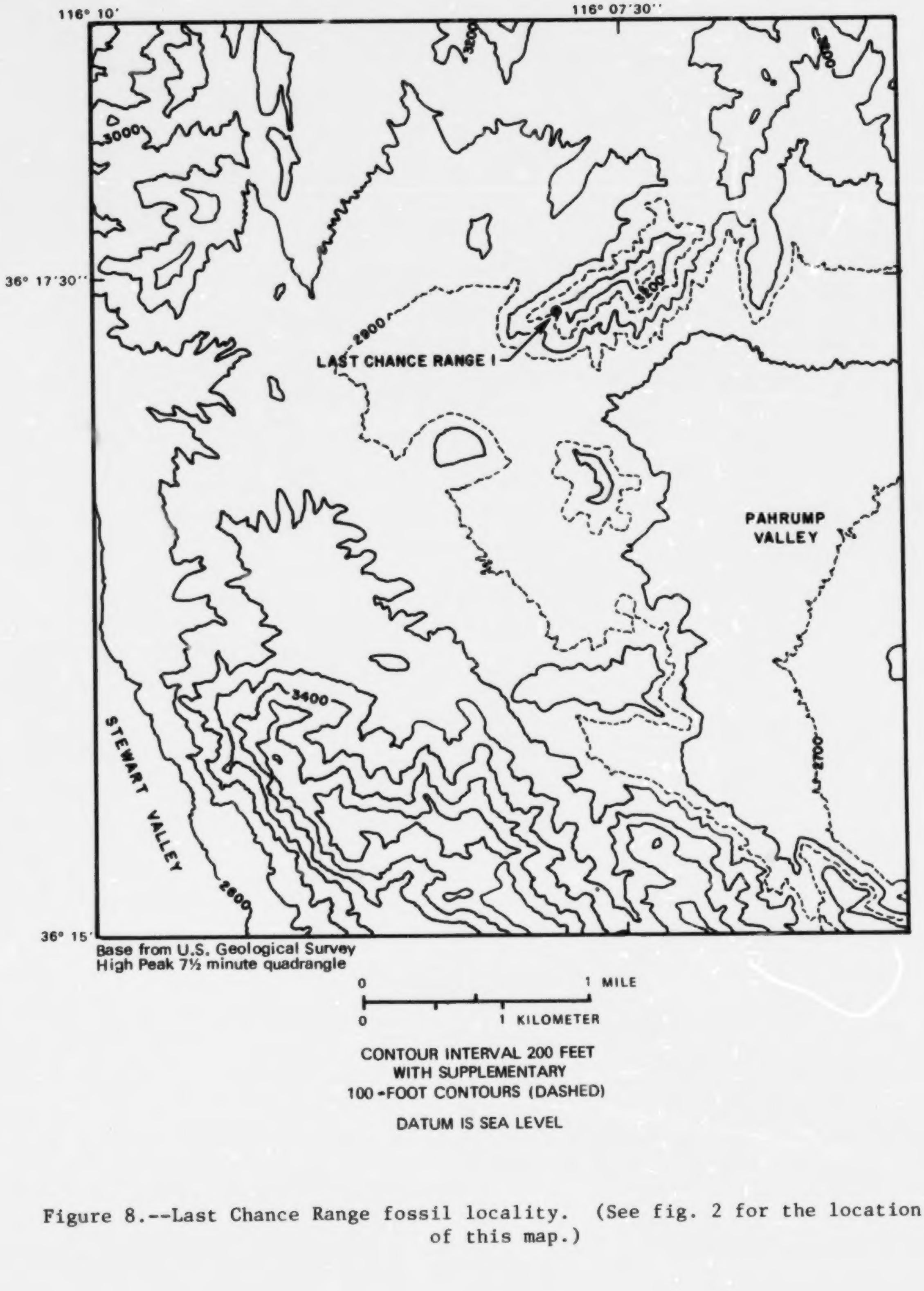


Figure 8.--Last Chance Range fossil locality. (See fig. 2 for the location of this map.)

These data indicate that, in general, cacti are not disproportionately abundant in the packrat middens sampled. Pricklypear (*Opuntia erinacea*) occurs in the vicinity of Eleana Range-3, and barrel cactus (*Echinocactus polycephalus*) grows close to the Owl Canyon-3, Specter Range-2, and Last Chance Range-1 sites. Neither species is well-represented in those respective middens. Nor is the beavertail pricklypear (*Opuntia basilaris*) (armed with many small spines) well-represented in the Owl Canyon-3 or Last Chance Range-1 assemblages.

Limber pine (*Pinus flexilis*) macrofossils occur as contaminants in recent midden debris from the Eleana Range-3 site. These three needle-fragments probably came from the large Pleistocene midden less than 2 m away, pieces of which litter the floor of the rock shelter. As both Cole (1981, p. 58-60) and Phillips (1977, p. 36) note, older material may contaminate a younger midden. However, recognizable contaminants of Wisconsin age (such as juniper twigs) were not found in recent midden debris from the Owl Canyon-3, Last Chance Range-1, or Specter Range-2 sites, even though each of these shelters also contains an ancient midden.

In summary, it appears the important plant species in the vegetation are not always important constituents of modern packrat debris piles. However, the inverse of this observation is not necessarily true. The abundant taxa in the middens are at least common constituents of the surrounding vegetation. Variations in proportionality appear to include bias both for and against individual plant species. Invariably there seem to be several species present in the modern vegetation that are not observed in the midden debris, and several species in the midden that are not found within the arbitrary 30-m foraging radius. The practical upper limit of Sorensen's (1948) similarity indices between middens and contemporary vegetation appears to be about 85 percent where plant communities are reasonably diverse (more than 15 woody species within a 30-m radius).

Climatic Reconstruction

Inferences of past climate are made from plant fossils and are based on the premise that there have been no significant changes in environmental requirements of these species during the last 50,000 years. There is abundant evidence for stability in the morphology of the species used as climatic indicators; however, the hypothesis that genotypes are stable over such time periods is untestable. This study presents quantitative climatic reconstructions based on changes in plant-species distribution and comparisons between estimated climate considered necessary to support a given fossil-plant association and climate that currently exists at that site. Two sources of modern climatic data are used. The first source is data collected by Beatley (1974, 1976) for the express purpose of delimiting climatic variables responsible for present vegetation distribution in the Nevada Test Site. The second source is U.S. Weather Bureau records of precipitation and temperature for six selected stations in Nevada (table 4). Four stations (Beatty, Eureka, Ely, and Austin) are in upland settings rather than near valley bottoms; the environment at these sites is more comparable to that of upland fossil sites. The two data sets are not directly comparable because the instrument stations used by Beatley (1974, p. 250) were at plant level (30 cm), and of different design than those of the U.S. Weather Bureau (at 1.5-m height). Temperature values presented by Beatley (1974, p. 250) are obtained from maximum-minimum thermometers; mean values are derived by averaging extreme temperatures recorded during the 2-week interval between readings.

Table 4.--*Temperature and precipitation data from six stations in Nevada*

[Data from U.S. Weather Bureau, 1965, and Environmental Data Service, 1961-78. Abbreviations for vegetation types are: Gds, Great Basin desertscrub; Mds, Mojave desertscrub; wd, pinyon-juniper woodland. m, meter; mm, millimeter; °C, degrees Celsius]

Station (vegetation)------------	Beatty (Mds)				Winnemucca (Gds)				Elko (Gds)			
North latitude; west longitude--	37°00'; 116°43'				40°54'; 117°48'				40°50'; 115°47'			
Elevation (m)-------------------	1,082				1,311				1,547			
Parameter-----------------------	Average temperature (°C)			Average precipitation (mm)	Average temperature (°C)			Average precipitation (mm)	Average temperature (°C)			Average precipitation (mm)
	January	July	Annual		January	July	Annual		January	July	Annual	
1931-60-------------------------	---	---	---	---	-2.1	21.7	8.8	215.1	-4.9	20.8	7.4	248.4
1961-78-------------------------	5.2	26.3	15.0	134.6	-1.2	22.3	9.4	205.4	-3.9	21.2	7.9	254.4
	[1]16	[1]16	[1]9	[1]17	---	---	[1]17	[1]17	---	---	---	---

Station (vegetation)------------	Austin (wd)				Eureka (wd)				Ely (wd/Gds)			
North latitude; west longitude--	39°30'; 117°05'				39°31'; 115°58'				39°17'; 114°51'			
Elevation (m)-------------------	2,014				1,994				1,906			
Temperature and precipitation--- parameter.	Average temperature (°C)			Average precipitation (mm)	Average temperature (°C)			Average precipitation (mm)	Average temperature (°C)			Average precipitation (mm)
	January	July	Annual		January	July	Annual		January	July	Annual	
1931-60-------------------------	-1.3	21.1	8.6	302.3	---	---	---	---	-5.6	19.7	6.8	221.0
1961-78-------------------------	-.8	21.4	8.6	364.9	-2.1	21.0	8.0	348.6	-4.9	19.7	6.8	244.7
	[1]17	[1]17	[1]14	---	[1]14	[1]14	[1]14	[1]14	---	---	---	---

---

[1] Number of years of record (1961-78) if less than 18.

The first step in these reconstructions is to estimate present climate of the fossil site. Data provided by Beatley (1974, table 1) are used to extrapolate estimated ranges of temperature and precipitation at fossil localities. One uncertainty is that most midden sites are on steep slopes, where orientation to the sun and relative elevation are important determinants of local climate. In contrast, Beatley's stations are on gentle slopes where orientation and relative altitude are less important, but where the effect of nocturnal cold-air drainage may be more pronounced. Such factors were considered when the current climatic parameters for critical fossil localities were estimated (table 5). The second step is to estimate the climate represented by a given fossil-plant assemblage, a process with even more uncertainties. In this analog approach, dominant plant species in macrofossil assemblages are assumed to characterize the local paleocommunity. If, for example, a midden contains abundant juniper and sagebrush with other Great Basin Desert shrubs, then temperature and precipitation values are estimated that coincide with sites at the lower limit of woodland in a relatively dry part of the State, where juniper grows with such shrubs today. In contrast, if a macrofossil assemblage contains abundant juniper and pinyon pine associated with woodland shrubs, then extrapolated climatic values are derived from sites that support such vegetation today, well above the lower limit of woodland. The range of present values at the fossil site are then substracted from estimated values for past climate to derive changes in mean annual temperature (ΔT) and precipitation. Precipitation change is expressed as a percent change from present values (percent P). Values of ΔT and percent P should be comparable, whether derived from Beatley's data base or U.S. Weather Bureau records, provided that separate sets of calculations consistently use one or the other. This approach represents only the first approximation to interpret an extensive fossil record.

Table 5.--*Estimated range of values for*

at four key fossil localities in

[Habitat abbreviations are: Af, alluvial fan; MR, mesa top or

for plant species are: Amdu, *Ambrosia dumosa*; Arno, *Artemisia nova*;

confertifolia; Gumi, *Gutierrezia microcephala*; Hysa, *Hymenoclea salsola*;

Pimo, *Pinus monophylla*; m, meter;

Site(s)	Elevation (m)	Orientation (from grid north)	Habitats			Vegetation		
			Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
Eleana Range-2 and -3	1,805	180°-205°	TL	MR	Af	Atca	Juos-Pimo	Arno-Artr
Specter Range-2	1,190	15°- 25°	TL	MR	--	Gumi-Prfa	Atco	--
Point of Rocks-1	900	147°-230°	TL	Af	W	Lypa-Gumi	Ladi	Hysa
Owl Canyon-2 and -3	795	180°-230°	TL	--	W	Amdu-Ladi	--	Gumi-Amdu

---

[1] From Beatley (1974, table 1).

mean annual temperature and precipitation

the Nevada Test Site and vicinity

ridge top; TL, talus slopes and ledges; W, dry wash. Abbreviations

Artr, *Artemisia tridentata*; Atca, *Atriplex canescens*; Atco, *Atriplex*

Juos, *Juniperus osteosperma*; Ladi, *Larrea divaricata*; Lypa, *Lycium pallidum*;

mm, millimeter; °C, degrees Celsius]

	Analogous climatic stations[1/]				Estimated values for fossil locality		
Site No.	Elevation (m)	Vegetation type	Mean precipitation (mm)	Mean temperature (°C)	Mean precipitation (mm)	Mean temperature (°C)	Remarks
61	1,756	Arno	206.0	12.4	215-225	11-12	Fossil locality less than 1 kilometer from sites 61 and 62.
62	1,750	Artr	205.5	11.9			
65	1,676	Atca	183.6	10.9			
2	1,088	Ladi	169.4	14.5	170-190	13-14	Fossil locality less than 1 kilometer from site 3.
3	1,038	do.	176.3	16.7			
4	1,055	do.	148.1	14.7			
30	943	Atca	126.0	13.5			
31	940	Atco	131.1	13.5			
1	1,027	Ladi	140.7	15.2	110-120	13.5-14.5	Fossil locality in the bottom of a canyon.
2	1,088	do.	169.4	14.5			
20	994	do.	136.4	14.7			
38	949	Lypa	121.9	13.7			
1	1,027	Ladi	140.7	15.2	105-115	16.5-17.5	--
7	963	do.	124.0	14.5			
8	938	do.	120.1	16.2			
9	989	do.	132.3	14.2			

Radiocarbon Dating

Questions concerning the dating of packrat middens are as critical as those addressing the representative nature of the plant macrofossil assemblage. It is assumed that macrofossils from a midden sample are contemporaneous within the standard deviation (1σ) of that sample's radiocarbon (^{14}C) age. The mixing of different-age macrofossils would lead to erroneous species associations, compromising paleoenvironmental reconstructions derived from them.

If the assumption of contemporaneity holds true, satisfactory dates could be obtained from any fraction of a packrat midden. Materials used for radiocarbon dating packrat middens range from whole samples of leafy strata and uriniferous residue (Wells and Jorgensen, 1964, p. 1172; Wells, 1977, p. 239) to *Neotoma* fecal pellets and fragments of single plant species (Van Devender, 1977a, p. 237). Because mixing of different-age material is a possibility, a monospecific date is a more reliable estimate of the age of occurrence of that species (Van Devender, 1973, p. 31-33; Phillips, 1977, p. 21-22; Cole, 1981, p. 32). Multiple radiocarbon dates, using different materials, should be used to verify the age of critical samples.

An assessment of 21 multiple-dating tests on packrat middens used in various studies (Spaulding, 1981, table 6) shows that 17 of the 58 radiocarbon dates were not within the expected age range at 1σ. Some of these tests were performed because contamination was suspected; excluding these tests leaves 11 dates that represent unanticipated discordancies. Caution is needed in evaluating macrofossil assemblages controlled by a single radiocarbon date.

A total of 71 samples were dated using carbon-14 techniques (table 6). Nineteen of the 46 macrofossil assemblages collected in the vicinity of the Nevada Test Site were dated at least twice. In addition, this study was designed to intensively sample large middens from a few sites to gain chronologic continuity at individual localities. Twelve middens from 7 localities were analyzed (table 6). Contrasts between samples thus could be used to identify anomalous assemblages that then were redated to verify their age.

The Eleana Range-3 packrat midden is of particular interest because of its great age and large size. It was subject to intensive radiocarbon analysis in an attempt to verify the ages of some of the oldest dated assemblages from the Southwest. Multiple dates are particularly important on samples with finite dates older than 30,000 years, when the quantity of radiocarbon remaining in a sample is extremely small. Materials dated were curl-leaf mountain mahogany (*Cercocarpus ledifolius*) and Utah juniper (*Juniperus osteosperma*) wood, limber-pine (*Pinus flexilis*) seed coats, *Neotoma* fecal pellets, unidentified twigs, and undifferentiated organic debris (a mix of sticks, fecal pellets, and plant fiber) (table 6). Other than the wood and seeds, monospecific samples could not be dated. Fragments of a single plant taxon rarely were abundant enough to provide the minimum 10 g desired to date a sample older than 30,000 years.

Table 6.—*Packrat-midden sites, samples, and radiocarbon dates*

[Artr, *Artemisia* sec. Tridentatae; Cele, *Cercocarpus ledifolius*; fp, *Neotoma* fecal pellets; Juos, *Juniperus osteosperma*; lv, leaves; Mout, *Mortonia utahensis*; Pifl, *Pinus flexilis*; sd, seeds; tg, twigs; uod, undifferentiated organic debris; upd, unidentified plant debris; wd, wood; Yusc, *Yucca schidigera*; 1σ, 1 standard deviation]

Site	Unit	Sample No.	Radiocarbon date (±1σ)	Laboratory No.[1]	Material dated	Weighted average[2]
Eleana Range (ER) 2	I	ER-2(1)	10,620±120	USGS-876	Juos tg & sd	---
(lat 37°07'18" N.,	I	ER-2(2)	11,700±85	USGS-914	Artr tg	---
long 116°14'03" W.,	II	ER-2(3)	13,180±65	USGS-884	fp	---
elevation 1,810 m).	II	ER-2(4)	14,090±320	A-2927	Pifl lv	---
	II	ER-2(4)	15,300±130	USGS-875	Pifl wd	---
	III	ER-2(5)	14,260±110	USGS-874	Pifl wd	---
	IV	ER-2(6)	14,500±110	USGS-885	Pifl lv	---
	IV	ER-2(6)	14,830±80	USGS-886	fp	14,720±70
	IV	ER-2(7)	14,760±100	USGS-887	fp	---
	IV	ER-2(7)/ 2(8)	15,380±100	USGS-888	Cele wd	---
	IV	ER-2(9)	15,890±120	USGS-889	fp	---
	IV	ER-2(10)	17,100±130	USGS-890	fp	---
	IV	ER-2(10)	17,100±90	USGS-1069	Pifl lv	17,100±70
	V	ER-2(11)	10,800±90	USGS-892	upd	---
	V	ER-2(11)	14,310±110	USGS-893	fp	---
Eleana Range (ER) 3	I	ER-3(2)	$49,800^{+3,100}_{-2,300}$	USGS-971	uod	---
(lat 37°07'15" N.,	I	ER-3(2)	42,500±1,300	USGS-1260	fp & tg	---
long 116°13'49" W.,	I	ER-3(3)	37,400±1,000	USGS-915	upd	---
elevation 1,800 m).	I	ER-3(3)	39,400±760	USGS-991	uod	38,670±610
	II	ER-3(4)	37,950±450	USGS-972	fp	---
	II	ER-3(4)	42,800±1,000	USGS-1261	tg	---
	III	ER-3(6)	40,600±850	USGS-973	uod	---
	III	ER-3(7)$_1$	$49,900^{+1,900}_{-1,500}$	USGS-916	Cele wd	---
	III	ER-3(7)$_2$	44,500±1,100	USGS-974	fp	---
	III	ER-3(7)$_2$	$46,100^{+1,200}_{-1,600}$	USGS-975	uod	45,110±870
	IV	[3]ER-3(p)	38,600±1,100	USGS-687	upd	---
	V	ER-3(8)$_2$	44,100±1,300	USGS-917	Cele wd	---
	V	ER-3(8)$_3$	39,800±1,200	USGS-918	Cele wd	---
	V	ER-3(8)$_3$	37,600±350	USGS-976	fp	37,770±340
	VI	ER-3(9)	34,800±550	USGS-1264	uod	---

Table 6.--*Packrat-midden sites, samples, and radiocarbon dates*--Continued

Site	Unit	Sample No.	Radiocarbon date (±1σ)	Laboratory No.[1]	Material dated	Weighted average[2]
Eleana Range (ER) 3 (cont.)	VI	ER-3(9)	36,290±330	USGS-1061	fp	---
	VI	ER-3(10)	$47,100^{+2,600}_{-2,000}$	USGS-919	Juos wd	---
	VI	ER-3(10)	32,500±800	USGS-993	fp	---
	VI	ER-3(10)	35,450±650	USGS-1265	uod	---
	VIII	ER-3(12)	45,400±1,500	USGS-920	Cele wd	---
	IX	ER-3(13)	22,940±150	USGS-992	fp	---
	IX	ER-3(13)	29,120±170	USGS-1062	upd	---
	---	[4]ER-3(u)	40,500±1,000	USGS-977	uod	---
	---	[5]ER-3(14)	14,200±100	USGS-1266	Pifl sd	---
Specter Range (Spc) 1 (lat 36°38'31" N., long 116°05'00" W., elevation 1,040 m).	---	Spc-1(1)	300±40	UW-635	upd	---
	---	Spc-1(2)	100^{+200}_{-100}	UW-630	Yusc lv	---
Specter Range (Spc) 2 (lat 36°40'16" N., long 116°12'33" W., elevation 1,190 m).	I	Spc-2(2)$_1$	18,760±110	USGS-1063	uod	---
	I	Spc-2(2)$_1$	18,710±150	USGS-994	Juos tg & sd	18,740±90
	I	Spc-2(2)$_2$	21,400±1,200	UW-637	Pimo lv	---
	I	Spc-2(2)$_2$	19,080±370	UW-638	Juos tg & sd	19,280±350
	II	Spc-2(3)	23,330±150	USGS-998	Juos tg	---
	II	Spc-2(3)	23,250±100	USGS-1064	uod	23,270±80
	II	Spc-2(6)	25,900±260	USGS-995	Juos tg & uod	---
	III	Spc-2(8)	27,900±300	USGS-997	Juos tg & sd	---
	III	Spc-2(8)	29,810±280	USGS-1065	uod	---
	III	Spc-2(10)	29,140±310	USGS-1066	uod	---
	III	Spc-2(11)$_1$	32,260±2,800	UW-639	Juos tg & sd	---
	III	Spc-2(11)$_2$	32,100±1,400	UW-640	Juos tg & sd	---
	IV	Spc-2(12)	25,280±220	USGS-996	Juos tg	---
	IV	Spc-2(12)	25,060±190	USGS-1067	uod	25,150±140
Specter Range (Spc) 3 (lat 36°40'35" N., long 116°12'28" W., elevation 1,100 m).	---	Spc-3A(1)	20,200±1,800	A-2398	Juos tg & sd	---
	---	Spc-3A(2)	10,660±250	A-2399	fp	---
	---	Spc-3A(2)	13,090±320	A-2400	Juos tg	---
	---	Spc-3B	28,460±2,200	A-2401	Juos tg	---

Table 6.--*Packrat-midden sites, samples, and radiocarbon dates*--Continued

Site	Unit	Sample No.	Radiocarbon date (±1σ)	Laboratory No.[1]	Material dated	Weighted average[2]
Point of Rocks (PR) 1	---	PR-1(1)	9,880±190	A-2395	fp	---
(lat 36°34'13" N.,	---	PR-1(1)	9,780±230	A-2396	upd	9,840±150
long 116°04'45" W.,	---	PR-1(3)	11,680±650	A-2397	upd	---
elevation 900 m).						
Point of Rocks (PR) 2	---	PR-2(2)	9,560±220	A-2393	upd	---
(lat 36°33'48" N.,	---	PR-2(3)	9,260±180	A-2394	upd	---
long 116°04'55" W.,						
elevation 930 m).						
Point of Rocks (PR) 3	---	PR-3	14,810±400	A-2927	tg	---
(lat 36°34'10" N.,						
long 116°05'10" W.,						
elevation 910 m).						
Owl Canyon (OC) 1[6]	---	OC-1	13,150±500	I-4237	Juos tg	---
(lat 36°24' N.,						
long 116°14' W.,						
elevation ca. 790 m).						
Owl Canyon (OC) 2	---	OC-2(1)	10,260±520	A-2402	fp	---
(lat 36°24'27" N.,	---	OC-2(2)	10,070±220	A-2403	fp	---
long 116°14'23",						
elevation 800 m).						
Owl Canyon (OC) 3	---	OC-3(1)	32,870±1,370	A-2412	Juos tg & sd	---
(lat 36°24'18" N.,	---	OC-3(2)	>28,700	A-2413	Juos tg & sd	---
long 116°14'29" W.,						
elevation 790 m).						
Last Chance Range (LCR) 1	---	LCR-1(2)	9,280±210	A-2414	Mout lv	---
(lat 36°17'25" N.,	---	LCR-1(3)	11,760±90	A-2415	Juos tg & sd	---
long 116°07'40" W.,						
elevation 960 m).						

---

[1] USGS, U.S. Geological Survey Radiocarbon Laboratory; A, University of Arizona, Laboratory of Isotope Geochemistry; UW, University of Washington, Department of Chemistry Radiocarbon Laboratory; I, Teledyne Isotopes.

[2] Average of paired dates from one sample, weighted toward the radiocarbon date with the smaller σ (the more precise date) (Long and Rippeteau, 1974, p. 208).

[3] Prospect sample removed prior to detailed stratigraphic analysis.

[4] Sample from loose float on floor of shelter.

[5] Loose fill in cavity between two indurated midden units.

[6] Midden located and collected by P. J. Mehringer, Jr. (Mehringer and Warren, 1976). The site could not be relocated.

Most of the units from the Eleana Range-3 midden appear to be contaminated. Multiple-dating tests were done on eight assemblages after the first series of radiocarbon ages failed to demonstrate normal superposition (fig. 9). Only one of the assemblages yields paired dates that are concordant at 1σ, ER-3$(7)_2$ (table 6). Multiple ages on samples ER-3(3) and 3$(8)_3$ overlap at 2σ. The range of dates from the midden is from 14,200 to 49,900 B.P. (radiocarbon years before the present) (table 6). Anomalously young ages occur at the bottom of two of the three sample columns (fig. 9). Dates on large pieces of wood were as much as 15,000 years older than on associated midden material; such contamination of younger strata with older debris may occur more often in large rock shelters and caves, where fossil material may be readily available. Packrats apparently may incorporate older sticks that were foraged from other parts of the shelter into a midden. Thus, large pieces of wood may be undesirable as dating material, because of their attractiveness as materials for packrat-den construction.

Some of the galleries behind and between ledges of indurated midden contain different-age organic debris. A tunnel-like cavity between samples ER-3(13) and 3(14) that extends to the back wall of the shelter (fig. 9) was filled with loose reddish-brown dirt and seeds. Limber-pine seed shells from this fill were dated at 14,200 B.P. (table 6). This indicates that at least part of the midden was occupied during the late Wisconsin as well as during the middle Wisconsin.

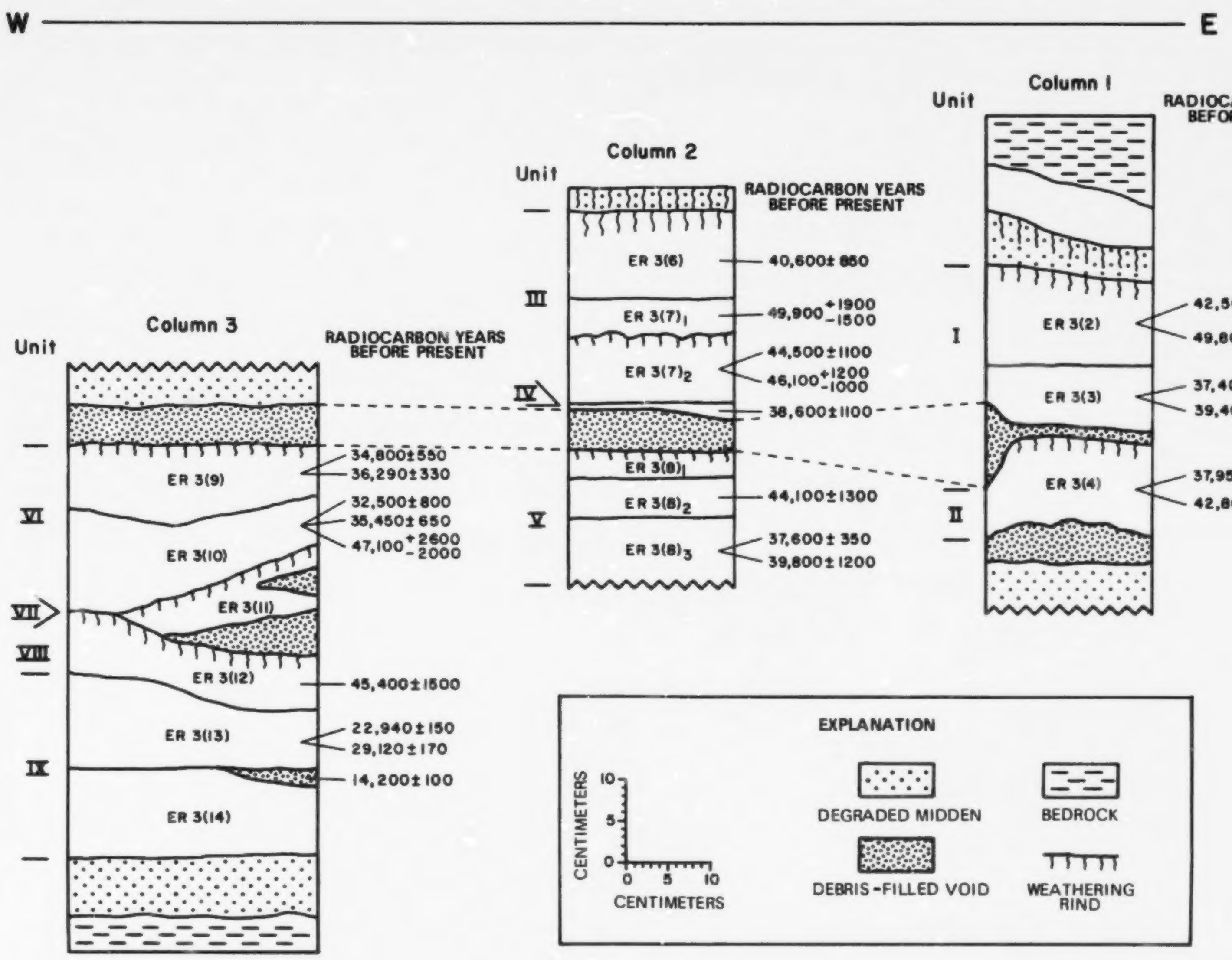


Figure 9.--Sample columns from the Eleana Range-3 packrat midden (dashed lines indicate inferred correlations).

Van Devender (1973, p. 17-18) first noted that packrat middens do not necessarily contain normally superimposed layers and that a packrat may deposit debris beneath a ledge formed by an older indurated midden. Based on the radiocarbon analyses of the Eleana Range-3 midden, it seems appropriate to extend this observation to note that some, but by no means all, middens may be so reworked by packrats throughout the millenia that they are undesirable for detailed paleoenvironmental reconstruction, no matter what their age. Only three assemblages from this midden had paired dates that were concordant at 2σ (table 6); only these assemblages will be used for paleoenvironmental reconstruction. These samples, ER-3(3), $3(7)_2$, and $3(8)_3$, may possess enough temporal integrity to warrant detailed discussion.

Dating results on the Eleana Range-2 midden (site ER-2; 10,600 to 17,100 B.P.) are more encouraging. The first series of dates from the midden revealed that normal superposition appears to be the rule rather than the exception (table 6). However, the lowermost unit yields anomalously young dates (fig. 10). This stratum also is friable and contains more insect fragments than the units above. The abundant mouse and pika (_Ochotona_ sp.) feces suggest reworking by burrowing animals subsequent to initial deposition. Paired radiocarbon dates of 14,310 (on _Neotoma_ feces) and 10,800 B.P. (on undifferentiated plant debris) (table 6) from sample ER-2(11) indicate that a mixing of older and younger material has occurred.

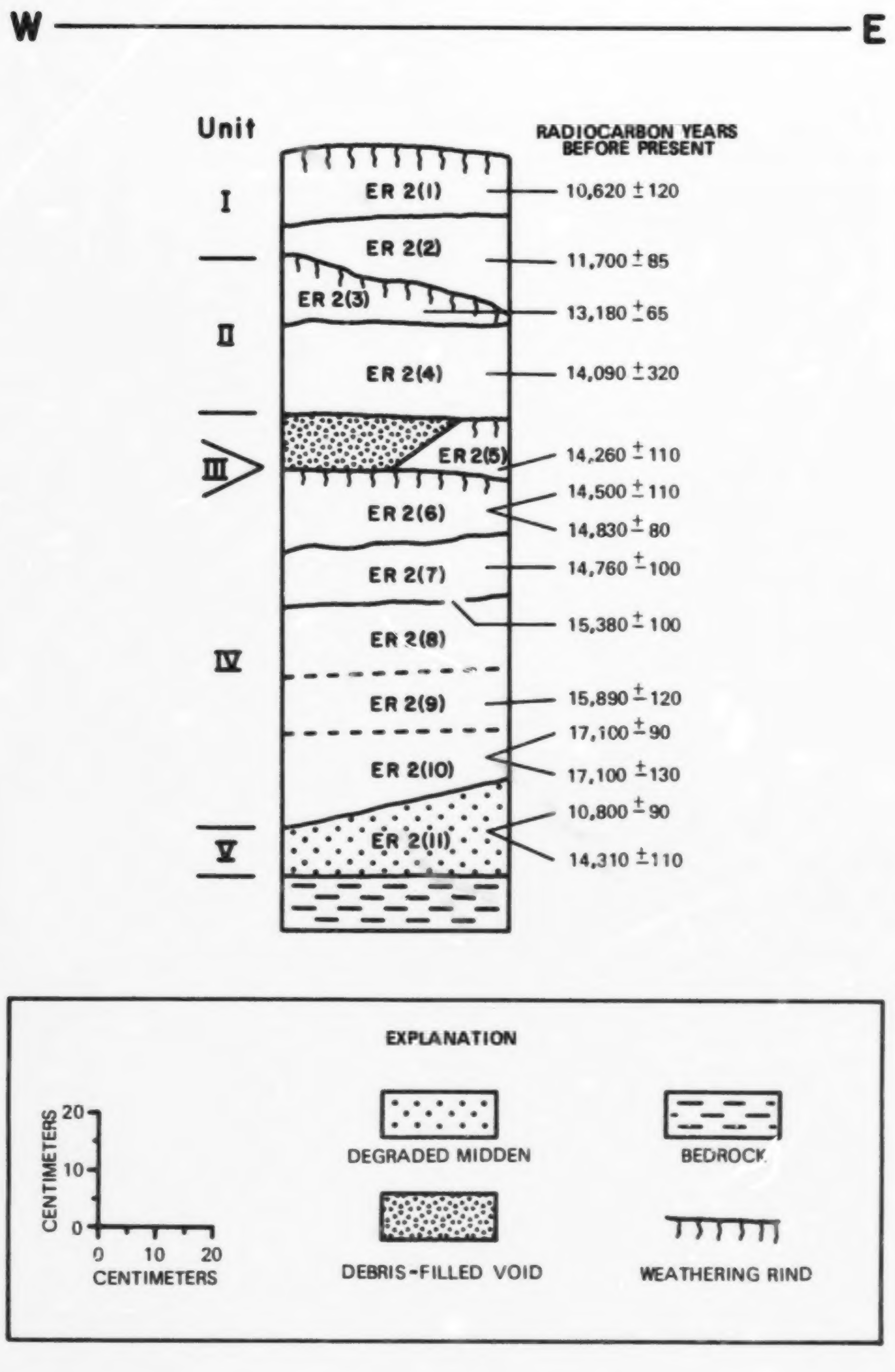


Figure 10.--Sample column from the Eleana Range-2 packrat midden.

Radiocarbon analyses of samples from the Specter Range-2 midden (site Spc-2; 18,700 to 32,000 B.P.) also indicate normal superposition of layers, with the exception again of the bottom stratum. Dates on sample Spc-2(12) are considerably younger than those from overlying strata (fig. 11; table 6). Unlike the dates on the lowest sample from the Eleana Range-2 midden, paired dates from sample Spc-2(12) are coeval at 1σ, yielding no evidence of mixing of different-age debris. This may be because the Specter Range-2 midden is suspended about 1 m above the floor of the rock shelter, perhaps precluding the bioturbation that occurs in the lower parts of middens that rest on rock-shelter floors.

THE FOSSIL RECORD IN SELECTED AREAS

Fossil packrat-midden sites in south-central Nevada can be placed into two categories. The first are those sites that lie within the floristic Mojave Desert, with middens that record vegetation on dolomite, limestone, or derived calcareous fanglomerates. In the vicinity of the Nevada Test Site, these range from elevations as low as 790 m in the Amargosa Desert, to 1,830 m in the Spotted Range (figs. 1, 2). The second category are midden sites from the Eleana Range in the floristic Great Basin Desert (figs. 1, 4). These rock shelters, developed in volcanic tuffs, lie at an elevation of about 1,800 m. Detailed lists of fossils from these sites are given in the Supplemental Data section, tables 16-25.

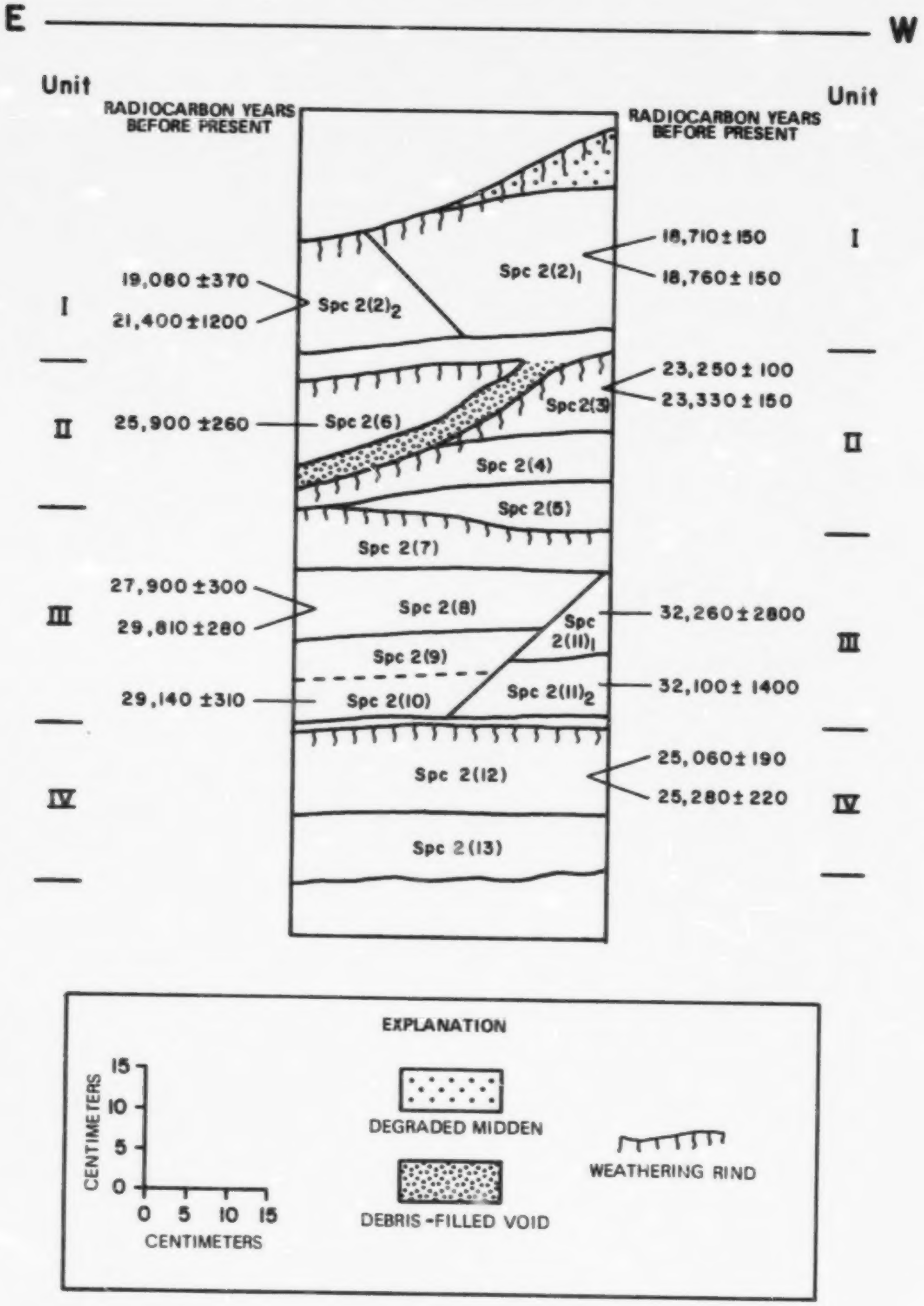


Figure 11.--Sample column from the Specter Range-2 packrat midden.

Periphery of Amargosa Desert

The lowest midden sites in the region are on the eastern edge of the Amargosa Desert, at elevations ranging from 790 to 960 m (fig. 1). These are also the only sites that provide records of glacial-age desert vegetation. Macrofossil assemblages from the Owl Canyon locality (fig. 7) date to the middle and latest Wisconsin (table 6). Present vegetation is sparse Mojave desertscrub on xeric dolomitic substrate. The most common plants on the rock slopes include matchweed (*Gutierrezia microcephala*) desert spruce (*Peucephyllum schottii*), white bursage (*Ambrosia dumosa*), and creosote bush (*Larrea divaricata*). The site of the Owl Canyon-1 midden, collected and dated by P. J. Mehringer, Jr., could not be relocated. It is near the mouth of the same canyon where the Owl Canyon-2 site is located (fig. 7; P. J. Mehringer, Jr., Washington State University, oral commun., 1980). Radiocarbon dated at 13,150±500 B.P. [laboratory number I-4237 (table 6)] (Mehringer and Warren, 1976, p. 125), this midden contains abundant Utah juniper (*Juniperus osteosperma*) and Utah agave (*Agave utahensis*), indicating an open woodland at Owl Canyon-1 near the end of the Wisconsin (Spaulding, 1981, p. 152).

The two other sites, Owl Canyon-2 and 3, are on xeric south-facing slopes (fig. 7), and are of different age. Macrofossil assemblages from Owl Canyon-3, at an elevation of 790 m, contain abundant rubber rabbitbrush (*Chrysothamnus nauseosus*) juniper, and common Utah agave, and they date to the middle Wisconsin (about 33,000 B.P. and >29,000 B.P.) (table 6). Both rubber rabbitbrush and Utah agave are characteristic of higher elevation deserts. Agave is not known below elevations of about 1,200 m (Beatley, 1976, p. 269). The abundance of shrubs and succulents in the Owl Canyon-3 assemblages may indicate desertscrub vegetation with occasional junipers, rather than a juniper woodland.

Two samples from the Owl Canyon-2 midden are radiocarbon-dated at 10,070 and 10,260 B.P. (table 6). They contain abundant Utah agave, but lack appreciable quantities of rabbitbrush and contain no juniper (see Supplemental Data section). Desertscrub vegetation apparently was well-developed at this site by the close of the Wisconsin. However, none of the xerophytic species that characterize the present local vegetation are recorded. Instead, the terminal-Wisconsin plant community appears to have been dominated by shrubs and succulents that commonly occur at higher elevations (above 1,200 m) today.

Late Wisconsin and early Holocene desert vegetation also is documented by packrat middens at the Point of Rocks locality. At an elevation of 910 m, the Point of Rocks-3 site is about 5 m above a talus slope head on the southwest-facing flank of a ridge (fig. 6). A sparse desertscrub community dominated by white bursage (Ambrosia dumosa), creosote bush, and chaff-bush (Amphipappus fremontii) occurs at the site today. The Point of Rocks-3 midden is dated at 14,810±400 B.P. (table 6) and contains abundant snowberry (Symphoricarpos longiflorus), an extralocal shrub, and common shadscale (Atriplex confertifolia) (see Supplemental Data section). It lacks the remains of juniper and, as such, it is the oldest reported macrofossil record of desertscrub vegetation from the American southwest.

The Point of Rocks-1 site, at an elevation of 900 m, is about 30 m from the floor of the large wash issuing into the Amargosa Desert from Point of Rocks Pass (fig. 6). A radiocarbon date of 11,680 B.P. on sample PR-1(3) (table 6) is associated with a macrofossil assemblage containing abundant cactus spines (Opuntia sp.) and the common twigs and flowers of scalebroom (Lepidospartum latisquamum) and matchweed. Like the Owl Canyon-2 and Point of Rocks-3 assemblages, sample PR-1(3) contains no arboreal species and is one of the first reported records of glacial-age desertscrub. Today, scalebroom is restricted to washes at elevations above 1,525 m (Beatley, 1976, p. 143). Its presence in this assemblage may indicate that some plant species in sample PR-1(3) were collected in the wash about 30 m away. Alternatively, conditions might have been such that this riparian species occurred on rocky slopes that are now too xeric to support it. Such a phenomenon has been noted in the midden record from the Sonoran Desert where some perennials, presently restricted to washes, occurred on hillsides during the late Wisconsin (Van Devender, 1973, p. 59). The younger PR-1(1) sample, dated at 9,840 B.P. (table 6), is dominated by desert bitterbrush (Purshia glandulosa), another extralocal species. Like the Owl Canyon-2 and 3 assemblages, those from Point of Rocks-1 document mesophytic desertscrub vegetation, dominated by species no longer near the site; with the exception of Owl Canyon-3, they contain no tree species.

Point of Rocks-2 site, at an elevation of 930 m, overlooks the alluvial fan that slopes westward to the Amargosa Desert, not far southwest of the Point of Rocks-1 site (fig. 6). At 9,260 and 9,560 B.P. the two desertscrub assemblages from Point of Rocks-2 are the youngest from the Amargosa Desert (table 6). Not coincidentally they contain more of the plant species that presently occur at the site, such as creosote bush and chaff-bush, than do the older midden samples from Point of Rocks-1 or Owl Canyon.

The highest elevation midden site on the periphery of the Amargosa Desert is in the western Last Chance Range at an elevation of 960 m (figs. 2, 8). The LCR-1C(3) assemblage is dated at 11,760 B.P. (table 6), less than 100 radiocarbon years older than the PR-1(3) assemblage. Nevertheless, in contrast to sample PR-1(3), LCR sample 1(3) contains abundant juniper, indicating that between 11,600 and 11,800 B.P., the lower limit of woodland in this area was not far above an elevation of 900 m. The LCR-1(2) assemblage, at 9,280 B.P., is of comparable age to the PR-2 samples (table 6). Like the Point of Rocks-2 assemblages, LCR-1(2) contains many of the plants that grow at the site today, although three of the four most abundant taxa are extralocal. Juniper was still present at this site at about 9,300 B.P., while it apparently was absent from the Point of Rocks and Owl Canyon localities well before this time.

Specter Range

Packrat middens from the northern Specter Range yield a different chronology of vegetation change. Macrofossil assemblages from the Specter Range-2 site, on the north side of a ridge at an elevation of 1,190 m (fig. 6), span more than 13,000 years, from about 32,000 to 18,700 B.P. (table 6). Mojave Desert vegetation at the site today contrasts with midden samples that indicate a middle Wisconsin juniper or juniper-shadscale woodland, and a pinyon pine (*Pinus monophylla*)-juniper woodland during the Wisconsin maximum.

The Specter Range-3 site, downslope and north of Specter Range-2 site, is less than 50 m from the head of an alluvial fan that extends into Rock Valley (fig. 8). The ages of sample Spc-3A(1) at 20,200 B.P. and sample Spc-3B at 28,500 B.P. are approximately contemporaneous with some of the Specter Range-2 samples (table 6). Like the Spc-2 record, these Spc-3 assemblages document a juniper woodland lacking pinyon pine, but contain greater proportions of shrubs, such as winterfat (*Ceratoides lanata*), sagebrush, and shadscale.

Preliminary onsite inspection of the Specter Range-1 midden, from the cliff bordering a large wash on the western edge of Mercury Valley (fig. 8), indicated it was younger than 3,000 B.P. However, it was collected and analyzed because a marked dichotomy was noted between plant fragments visible in the midden and the surrounding vegetation. The top layer has a radiocarbon date of 300±40 B.P., whereas the bottom unit is subrecent (100^{+200}_{-100} B.P.) (table 6). The older sample is dominated by fourwing saltbush (*Atriplex canescens*), whereas the younger sample contains abundant creosote bush.

Eleana Range

The Eleana Range is a southerly extension of the Belted Range and Pahute Mesa (fig. 2). Two adjacent sites on south-facing slopes, Eleana Range-2 and 3 (fig. 4), contain large indurated middens. Today, these sites are at the boundary between Great Basin desertscrub, occupying the talus slopes and valleys, and pinyon pine-juniper woodland, occurring on the mesa tops and north-facing slopes. The Eleana Range-2 midden records past vegetation from Wisconsin maximum to latest Wisconsin time. Samples from Units II through IV, from 13,200 to 17,100 B.P. (fig. 10), provide evidence for a limber-pine (*Pinus flexilis*) woodland with Great Basin Desert and woodland shrubs as important understory species. The two youngest samples (Unit I at 11,700 and 10,600 B.P.) (table 6) indicate a shift to a woodland dominated by juniper, pinyon pine, and pricklypear (*Opuntia erinacea*) species present in the modern woodland nearby.

As mentioned previously, radiocarbon analyses indicate that many assemblages from the complex Eleana Range-3 midden may be contaminated. Three samples that have statistically similar paired-radiocarbon dates, and thus may contain valid species associations are: (1) Sample ER-3$(8)_3$ at 39,800 B.P.; (2) sample ER-3(3) at 38,700 B.P.; and (3) sample ER-3$(7)_2$ at 45,000 B.P. [ages expressed are weighted averages of two ^{14}C dates on each sample (Long and Rippeteau, 1974)] (table 6). These assemblages reflect an open juniper woodland that differed from both late Wisconsin plant communities recorded by the Eleana Range-2 midden and the present vegetation. Extralocals, such as curl-leaf mountain mahogany (*Cercocarpus ledifolius*,) were present, and species important in the current woodland nearby were absent, such as Gambel oak (*Quercus gambelii*) and pinyon pine.

Early Records from the Nevada Test Site

Wells and Jorgensen (1964) were the first to report on the significance of ancient packrat middens. Their initial studies were conducted in the vicinity of the Nevada Test Site (fig. 2) where some indurated packrat middens were found to contain abundant juniper. The presence of this tree fossil at sites supporting only desert vegetation today led Wells' colleagues to suspect that the middens were of considerable antiquity (Wells, 1976, p. 224). Of this early series, the lowest elevation sites are from the Ranger Mountains and lie between elevations of 1,100 and 1,130 m (fig. 2). The Ranger Mountains-1 midden, dated at 16,800±300 B.P., contains a depauperate macrofossil assemblage, while samples from the Ranger Mountains-2 midden, dated variously from 10,100±160 to 28,900±1,200 B.P., contain abundant shadscale and common pricklypear (Wells and Berger, 1967, table 1). Mercury Ridge-3 (at 1,250 m) is the only other midden of Wisconsin age, dated at 12,700±200 B.P. The remaining middens from Mercury Ridge, as well as those from Aysees Peak and the Spotted Range, are all of early Holocene age. All contain juniper, and the Spotted Range-2 midden also contains common pinyon pine (*Pinus monophylla*), although there is a discrepancy in the radiocarbon dates for this midden (reported as >40,000 and 9,550±90 B.P.) (Wells and Jorgensen, 1964, table 1; Wells and Berger, 1967, table 1). These middens document the persistence of juniper at high desert sites more than 3,000 years after its extirpation from lower altitude sites in the Amargosa Desert (Spaulding, 1983).

Sheep Range and Eureka Valley

Only four mountain ranges in the Mojave Desert have considerable relief above 2,200 m, the approximate lower limit of montane vegetation in this region. From west to east, these ranges are the Inyo Mountains and Panamint Range of California and the Spring and Sheep Ranges of Nevada (fig. 1). Late Quaternary vegetation of the Sheep Range, 60 km east-southeast of the Nevada Test Site, has been the subject of a recent packrat-midden study (Spaulding, 1981). This record consists of 52 macrofossil assemblages from 30 sites that span 900 m of topographic relief. Sheep Range midden sites extend the fossil record from limestone and dolomite substrates to 2,400 m. Such rocks generally are lacking above an elevation of 1,600 m in the Nevada Test Site. Current vegetation of the Sheep Range is like that of the Nevada Test Site, given similar topography and parent rocks; the packrat-midden record also is similar. Below approximately 1,800-m elevation, Wisconsin age packrat middens from the southeastern Sheep Range (fig. 12) and the western Sheep Range (fig. 13) yield records of juniper-shrub vegetation analogous to records from sites such as Specter Range-2. Late Wisconsin middens from above 1,800-m elevation in the Sheep Range yield assemblages dominated by subalpine conifers (*Pinus flexilis* and *Pinus longaeva*) (Spaulding, 1981, fig. 27).

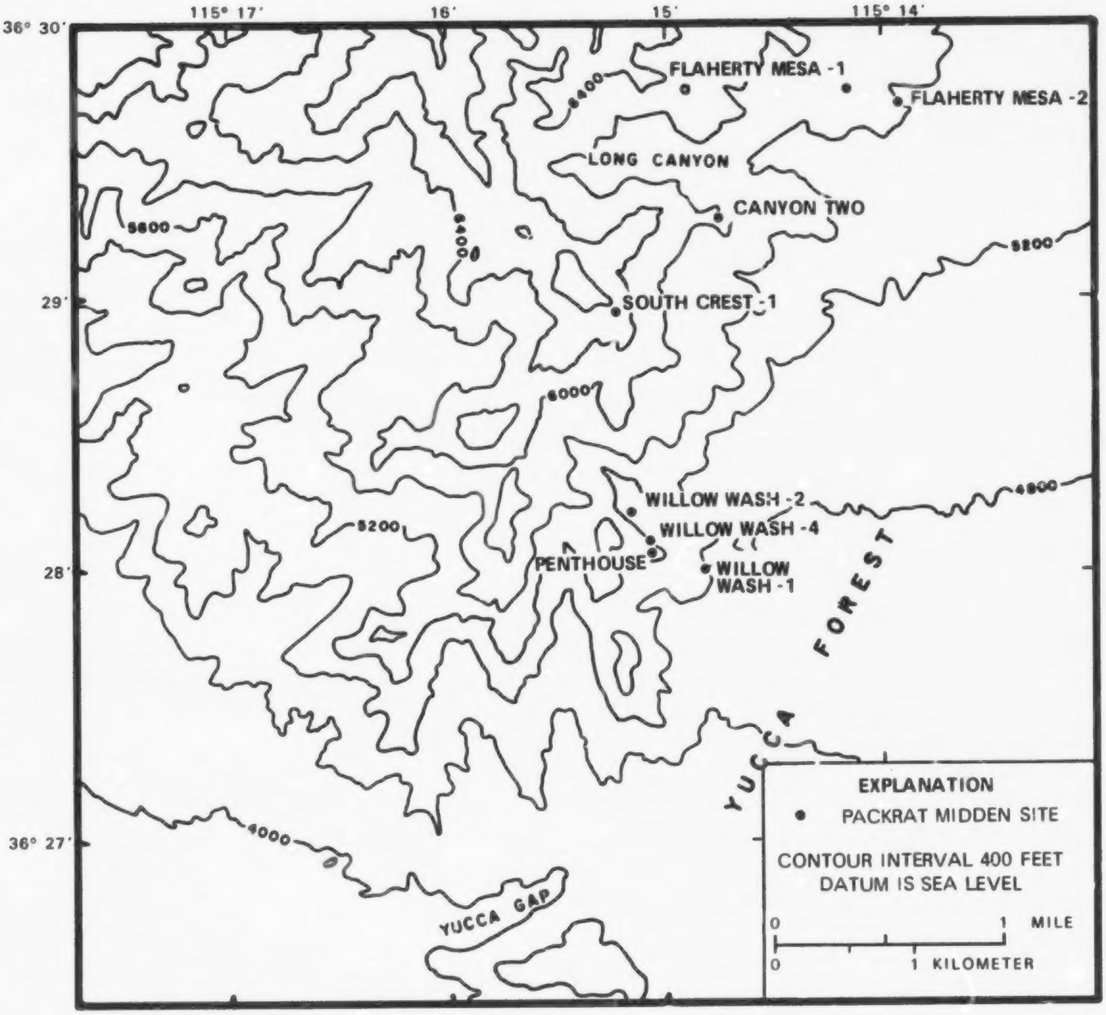
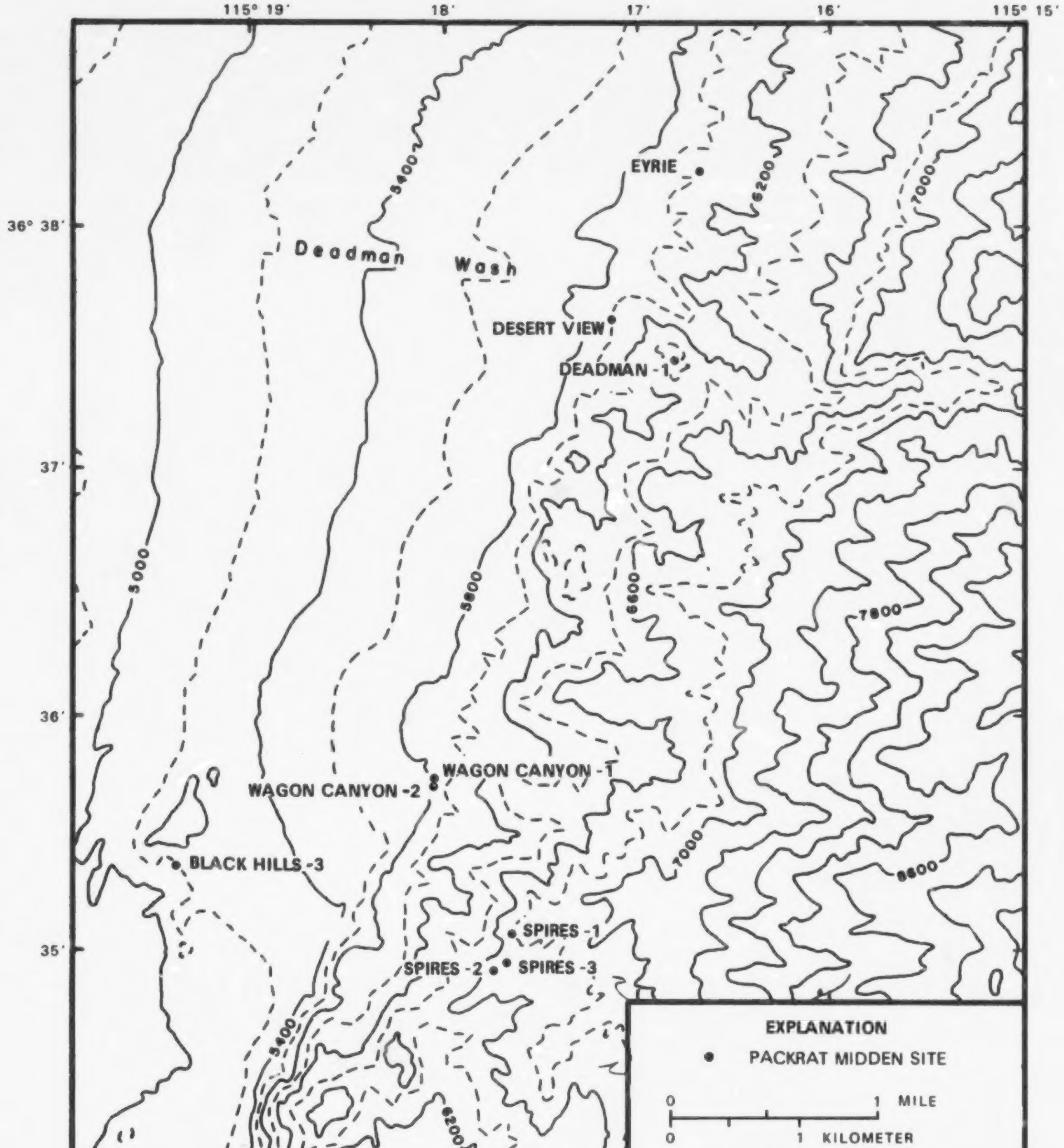


Figure 12.--Location of packrat-midden sites in the southeastern Sheep Range.



Base from U.S. Geological Survey
Black Hills and White Sage Flat
7½ minute quadrangles

Figure 13.--Location of packrat-midden sites in the western Sheep Range.

Midden data from the Sheep Range are synthesized in the regional fossil record of the northern Mojave Desert (fig. 14) with middens from the Nevada Test Site and vicinity. Two isolated records from the Blue Diamond area in the southern Spring Range (Spaulding, 1981, p. 153-157) and middens from the Eureka Valley in California, 140 km west-northwest of the Nevada Test Site (fig. 1) (Spaulding, 1980), also are included in figure 14.

Packrat middens from the Eureka Valley are the only comprehensive Holocene time series from the northern Mojave Desert (see Supplemental Data section, table 25) and supplement the midden record from the periphery of the Amargosa Desert. Middens from the Amargosa Desert document the presence of late Wisconsin and early Holocene desert vegetation that differed from current desertscrub. Eureka Valley middens show transformation of this anomalous desertscrub to an essentially modern vegetation type.

Explanation for Figure 14

----	Inferred position of major vegetation zone boundaries.
-------	Samples from volcanic substrate (the Eleana Range locality).
▲	Samples dominated by subalpine conifers.
△	Samples containing montane conifers.
•	Samples containing abundant Utah juniper.
◉	Assemblages with both abundant juniper and pinyon pine.
(•)	Samples with abundant juniper and common limber pine.
●	Anomalous desertscrub assemblages.
○	Desertscrub vegetation analogous to that at the site today.
——	± 1σ of that sample's radiocarbon date.

Abbreviations for the fossil localities from the vicinity of the Nevada Test Site and Amargosa Desert are: A, Aysees Peak; ER, Eleana Range; F, Funeral Mountains; LCR, Last Chance Range; M, Mercury Ridge; OC, Owl Canyon; PR, Point of Rocks; R, Ranger Mountains; S, Spotted Range; Spc, Specter Range (fig. 1). Abbreviations for sites from the Sheep Range are: BC, Basin Canyon; BH, Black Hills; BW, Basin Wash; CT, Canyon Two; Dm, Deadman; DV, Desert View; Ey, Eyrie; FM, Flaherty Mesa; HF, Hidden Forest; Ph, Penthouse; SC, South Crest; Sm, Sawmill Canyon; Sp, Spires; WC, Wagon Canyon; WW, Willow Wash (figs. 12, 13). The BDR (Blue Diamond Road) sites lie in the southeastern Spring Range, and the HTH (Horse Thief Hills) and EV (Eureka View) sites are in the northern Eureka Valley (fig. 1). Data are from this report, Wells and Berger (1967), and Spaulding (1980, 1981).

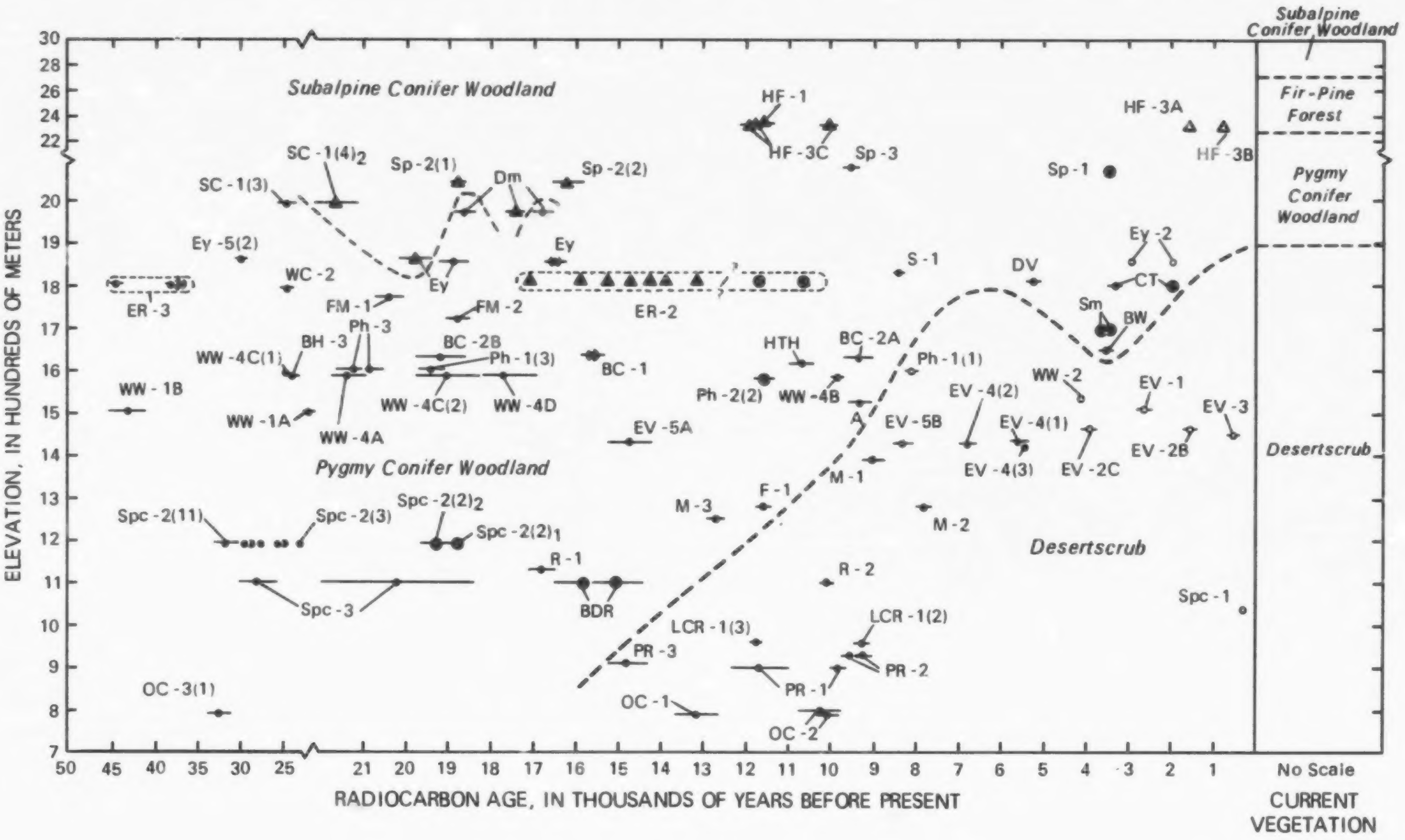


Figure 14.--Age and elevational distribution of late Quaternary packrat-midden samples from the northern Mojave Desert. [Dashed lines indicate the approximate elevation of major vegetation zone boundaries on xeric slopes. Note changes in scale. The column to the right presents the current vegetation zonation.]

Tule Springs

Pollen-stratigraphic and geologic investigations at Tule Springs, in the Las Vegas Valley about 80 km southeast of the Nevada Test Site (fig. 1), provided some of the first detailed information on the late Quaternary environments of the Mojave Desert (Martin and Mehringer, 1965; Mehringer, 1967; Haynes, 1967). Although some conclusions reached during this earlier work require revision (Spaulding and others, 1983), palynological evidence for the expansion of woodland and Great Basin Desert plants during the Wisconsin corroborates evidence provided by packrat middens from nearby mountains. Important paleoecological inferences from Tule Springs came from pollen spectra of spring mound sediments of latest Wisconsin age. Relatively high frequencies of *Juniperus* and *Artemisia* pollen, coupled with juniper wood in the sediments, indicates an open juniper woodland with Great Basin Desert species on the floor of the Las Vegas Valley (Mehringer, 1967, p. 184-185).

Grand Canyon

Wisconsin-age environments of the Grand Canyon have been the subject of several investigations. Packrat middens from the lower Grand Canyon of Arizona, 215 km east-southeast of the Nevada Test Site (fig. 1), provide an elaborate record from limestone slopes between elevations of 440 and 675 m (Phillips, 1977). Although current vegetation at most sites is desertscrub, late Wisconsin macrofossil assemblages document a juniper woodland with a diverse complement of desert species (such as *Atriplex confertifolia*, *Agave utahensis*, *Ephedra* sp., *Echinocactus polycephalus*) and some woodland associates (such as *Symphoricarpos* sp., *Opuntia whipplei*) (Phillips, 1977; Mead and Phillips, 1981). Many species common in the late Wisconsin woodland of the lower Grand Canyon, such as blackbrush (*Coleogyne ramosissima*), single-leaf ash (*Fraxinus anomala*), and brittlebush (*Encelia farinosa*), are rare or missing in similar-age middens from the Nevada Test Site and Sheep Range, partly because of the higher elevation of these Nevada sites. It also is probable that the precipitation regime of the Grand Canyon region was different from areas to the west and north. Assemblages in late Wisconsin packrat middens from farther east in the central Grand Canyon (Cole, 1981) are even more different from the Nevada fossil record, although these records are from the same altitudinal range.

The timing of latest Wisconsin vegetation change in the lower Grand Canyon was distinctly different from that recorded by packrat middens from the Nevada Test Site and vicinity. Grand Canyon sites as low as 560-m elevation supported juniper woodland well into the Holocene (until about 8,500 B.P.) (Phillips, 1977, p. 85; Van Devender, 1977b; Cole, 1982). In contrast, middens from the Amargosa Desert as high as 930-m elevation show that woodland gave way to desert vegetation by at least 14,800 B.P. at some localities (fig. 14) (Spaulding, 1983).

LATE QUATERNARY VEGETATION AND CLIMATE

The Wisconsin macrofossil record from the northern Mojave Desert spans 1,600 m of topographic relief, from Owl Canyon in the Amargosa Desert (800 m) to the Hidden Forest (2,400 m) in the Sheep Range (Spaulding, 1981, p. 144). The record provides a data base sufficient for estimates of paleoclimate that can be compared with estimates from other regions. Major environmental changes, such as that which occurred at the end of the Wisconsin, are evident in the composite packrat-midden record (fig. 14), but lower magnitude fluctuations can be better studied in time series from single midden sites. Plant community change usually takes place in the context of a single vegetation type; variations occurred in the composition of woodland during the Wisconsin, and changes occurred in desertscrub vegetation during the Holocene. Time series macrofossil assemblages at different sites, coupled with the use of relative frequencies of macrofossils, help discern these more subtle changes.

The Climate: Long-Range Investigation Mapping and Prediction (CLIMAP) project members' (1976, fig. 1) reconstruction of full-glacial (18,000 B.P.) surface conditions of North America shows the Southwest as a region of sparse vegetation with a high surface albedo. However, woodland was widespread in this region, with a resultant albedo that was lower than today's. The cause of this discrepancy is the assumption that lowered temperatures during the late Wisconsin led to reduced competency of the atmosphere and, therefore, to less precipitation and sparse vegetation. However, this was not the case. Lowered temperatures and increased winter precipitation during the full glacial led to decreased evapotranspiration, greater effective moisture, and increased vegetation cover in the arid West. The initial paleobotanical evidence for this difference (Martin and Mehringer, 1965; Mehringer, 1967; Wells and Berger, 1967) was not well depicted by CLIMAP (1976).

Middle Wisconsin Environments

The middle Wisconsin has been correlated with oxygen-isotope stage 3 in the deep-sea core record (Dreimanis and Raukas, 1975, p. 109-110 and 116), with bracketing dates of about 62,000 and 23,000 B.P. (Prell and Hayes, 1976, fig. 3; Ruddiman and McIntyre, 1981, fig. 2). Variations in the oxygen 16/oxygen 18 ($^{16}O/^{18}O$) ratios in the tests of benthic foraminifera in deep-sea cores provide an index of global ice volume (Shackelton and Opdyke, 1973) and indicate that interstadial conditions prevailed during this period. This was a time of generally lower continental ice sheet volume and warmer global temperatures, between the early and late Wisconsin stades [isotope stage 4 for the early Wisconsin and stage 2 for the late Wisconsin (Dreimanis and Raukas, 1975)].

Packrat-midden samples cannot be placed in a well-defined stratigraphic framework; each must be associated with a radiocarbon age. Because the practical upper limit of most radiocarbon-dating laboratories is about 30,000 B.P., only the last 7,000 years of the middle Wisconsin lie within the dating range of most studies. The relatively large number of finite dates from the Nevada Test Site that range from 30,000 to 45,000 B.P. are the result of radiocarbon assays performed at the high-precision facility of the U.S. Geological Survey at Menlo Park, California (Robinson, 1979).

45,000 to 35,000 Years Before Present

Four finite-age macrofossil assemblages from the northern Mojave Desert are older than 35,000 B.P. (fig. 14). The three from the Eleana Range-3 midden provide the oldest time series from a single site in the Southwest. The ER-3$(7)_2$ assemblage is associated with two radiocarbon dates with a weighted average of 45,000±900 B.P. (Long and Rippeteau, 1974) (table 6). It indicates vegetation broadly similar to today's: An open woodland of Utah juniper and mountain mahogany (Cercocarpus ledifolius), with well-developed stands of sagebrush (figs. 15, 16). Limber pine, the dominant tree during the succeeding full glacial, is absent from the ER-3$(7)_2$ sample, as are many of the plants present today (such as Pinus monophylla, Quercus gambelii, Rhus trilobata, and Atriplex canescens).

Based on the ER-3$(7)_2$ macrofossil assemblage, precipitation at about 45,000 B.P. is inferred to have been no higher than the present values of roughly 185 to 205 mm/yr^{-1} (table 5). Affinity of the fossil flora to present northern steppe and dry woodland suggests that a smaller proportion of precipitation fell during the summer (less than 10 percent as opposed to the present value of about 25 percent). Absence of thermophilous species, such as saltbushes (Atriplex spp.), hopsage (Grayia spinosa), and appreciable quantities of pricklypear (Opuntia spp.) from the ER-3$(7)_2$ sample implies an average annual temperature 1° to 3°C lower than at present (table 5).

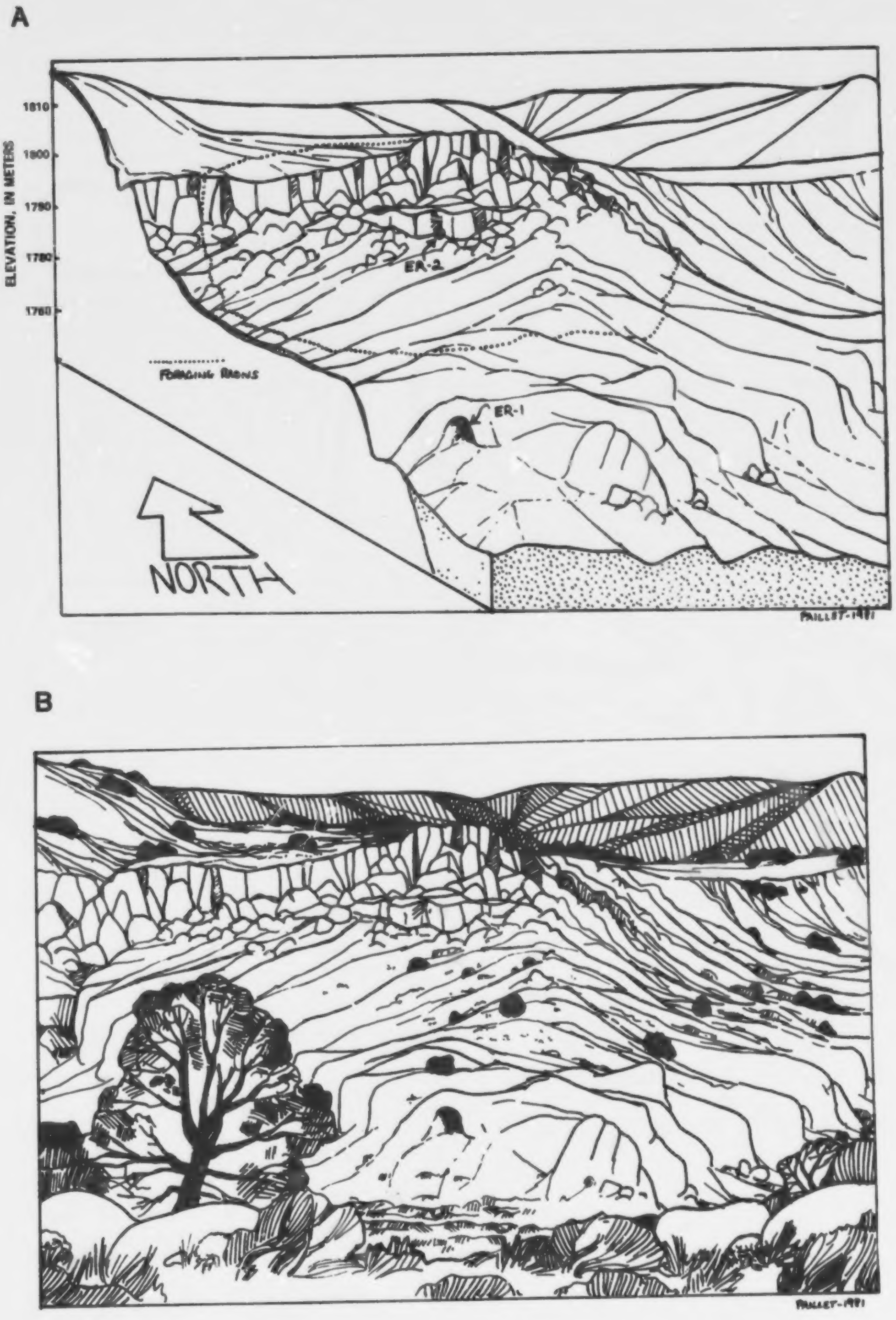


Figure 15.--Eleana Range fossil locality: A. Physiography of the Eleana Range-1 and 2 sites; B. Modern vegetaicn at the Eleana Range-1 and 2 sites. Sketches by Frederick Paillet, U.S. Geological Survey, 1981. (See fig. 4 for location of sites.)

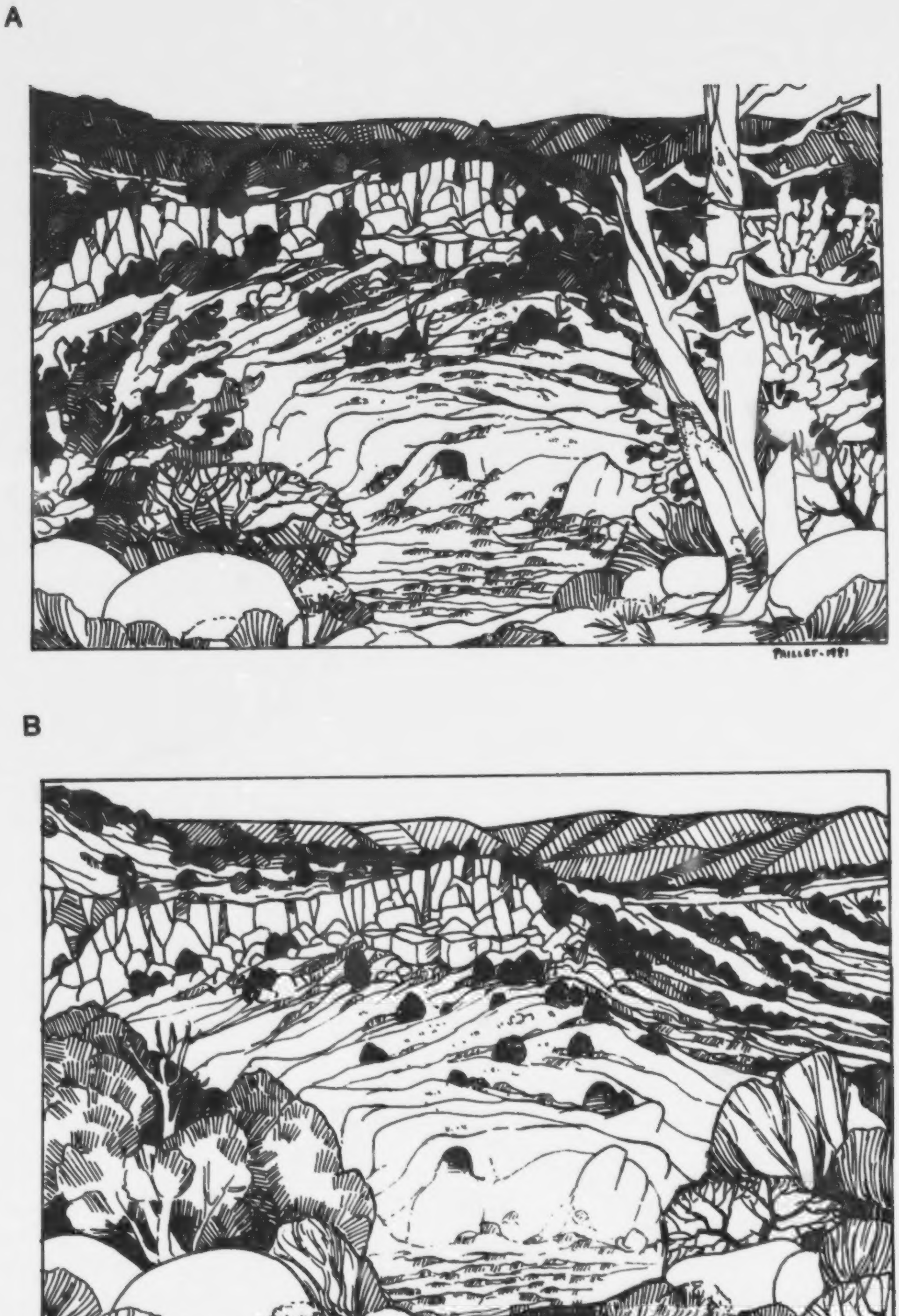


Figure 16.--Reconstructions of the Wisconsin vegetation of the Eleana Range: A. Full-glacial (Wisconsin maximum) limber-pine woodland; B. Juniper-steppe shrub vegetation during the middle Wisconsin (about 45,000 years ago). Sketches by Frederick Paillet, U.S. Geological Survey, 1981.

Only one other macrofossil assemblage from this region is broadly correlative with the ER-3(7)$_2$ sample: Willow Wash-1B from the southeastern Sheep Range (figs. 12, 14) (Spaulding, 1981, p. 86). Dated at 43,700±2,300 B.P. (USGS-548), this sample provides evidence for juniper woodland at a site that presently supports desertscrub vegetation, well below the lower limit of woodland (an elevation of 1,585 m). It is intriguing to note that, while the ER-3(7)$_2$ macrofossil assemblage bears a general resemblance to current dry woodland and steppe vegetation near the site (figs. 15, 16), the Willow Wash-1B juniper assemblage provides a greater contrast with present vegetation there. However, indices of similarity between these two samples and current vegetation at their respective sites are comparable, with a value of 40 for the ER-3(7)$_2$ sample and 36 for the Willow Wash-1B sample (Spaulding, 1981, table 39). This indicates that the apparent stronger contrast between the Willow Wash-1B fossils and current flora is primarily because a single species, Utah juniper, no longer occurs there. Species common in more mesic phases of today's woodland are missing from the Willow Wash-1B sample, as they are from the ER-3(7)$_2$ sample. The presence of several desert shrubs and succulents (such as *Opuntia whipplei* and *Hecastocleis shockleyi*) in the middle Wisconsin woodland at Willow Wash suggests that winter minimum temperatures were within 2° to 3°C of today's values.

Two younger assemblages from the Eleana Range-3 midden, ER-3(3) and ER-3(8)$_3$, have radiocarbon dates that overlap at 1σ (table 6). Macrofossils from these two assemblages suggest increased effective moisture and higher temperatures about 6,300 years after the deposition of ER-3(7)$_2$. *Artemisia* sec. Tridentatae frequencies are lower in both ER-3(3) and ER-3(8)$_3$; this decline is accompanied first by an increase in *Juniperus osteosperma* in ER-3(3) (dated at about 38,700 B.P.), and then *Pinus flexilis* and *Cercocarpus ledifolius* in ER-3(8)$_3$ (dated at about 37,800 B.P.) (table 6; fig. 17). The macrofossils of *Grayia spinosa* are a notable occurrence in ER-3(3). Normally restricted to desert communities, its presence here indicates that maximum mid-Wisconsin temperatures, within 1° to 2°C of present annual values, may have occurred around 38,700 B.P. The associated increase in juniper and decline in sagebrush frequencies (fig. 17) implies an increase in precipitation, perhaps 10 to 20 percent above today's values (table 5). This increase may have resulted in part from warmer summers and enhanced warm-season rainfall.

Macrofossils from the youngest sample in this interstadial sequence, the ER-3(8)$_3$ sample, at about 39,800 B.P., indicate highest effective moisture. *Juniperus osteosperma* is in part replaced by *Pinus flexilis* and *Cercocarpus ledifolius* (fig. 17). The importance of these dry woodland and subalpine species, coupled with the continued absence of plants of relatively mild-moist habitats (such as *Pinus monophylla*, *Pinus ponderosa*, *Quercus gambelii*), indicate the increase in effective moisture resulted from a temperature decline. Similar plant associations presently occur on south-facing slopes at about 2,800 m in the Toquima Range, 180 km to the north-northwest. The difference in elevation between analogous Toquima Range sites and Eleana Range-3 (about 1,000 m) indicates a decline of 5°C in mean annual temperature relative to present values, assuming an annual temperature lapse rate of -0.5°C/100 m (Major, 1977, p. 65 and 68). Average annual precipitation 10 to 20 percent greater than present values (table 5) also is consistent with the fossil record from the ER-3(8)$_3$ sample.

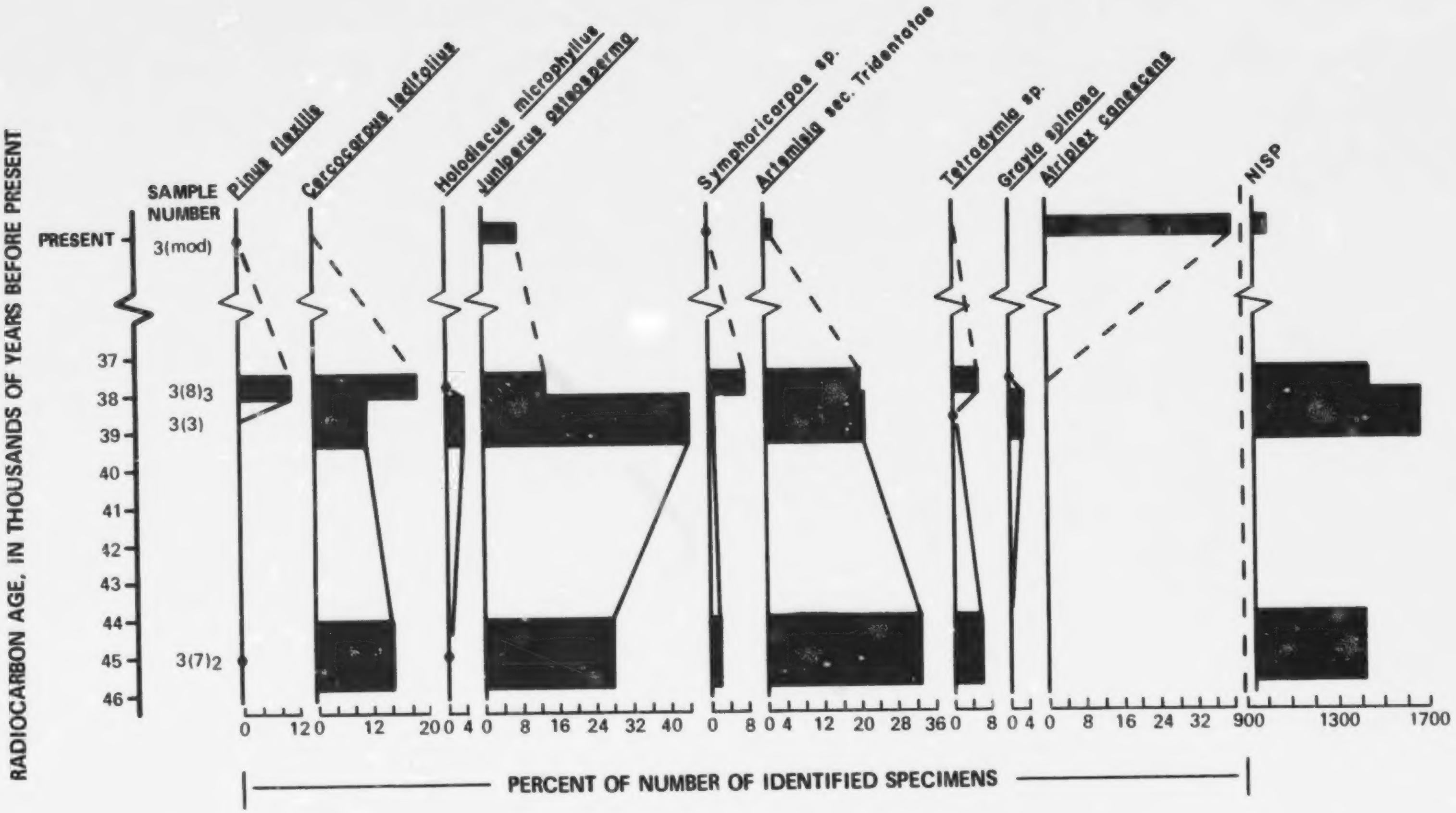


Figure 17.--Relative frequencies of selected plant taxa in macrofossil assemblages from the Eleana Range-3 midden. (Vertical width of the bars is proportional to ±1σ of the sample's radiocarbon date, except for the ER-3 (modern) sample assemblage; solid circle represents ≤1 percent of number of identified specimens.)

35,000 to 23,000 Years Before Present

Thirteen macrofossil assemblages from the northern Mojave Desert date to the latest part of the middle Wisconsin. Specter Range-2 site at an elevation of 1,190 m provides the only detailed chronosequence from this period. The oldest assemblages are rather poorly dated at about 32,000 B.P. (Spc-2$(11)_1$ and $2(11)_2$) (table 6). In contrast to current Mojave desertscrub vegetation at the site, these samples contain abundant Utah juniper, as well as abundant-to-common shadscale (Atriplex confertifolia) and rock spirea (Petrophytum caespitosum). Five younger samples, ranging in age from 29,100 to 23,300 B.P., also contain abundant Utah juniper (fig. 18).

Rock spirea is a mesophytic petrophyte (rock-loving plant) now extinct in the Specter Range. Scopulophila rixfordii, on the other hand, is a thermophilous petrophyte still present nearby. It is not surprising that variations in relative frequency of these taxa in the Specter Range-2 assemblages are inversely related (fig. 18). These fluctuations may represent short-term changes in effective moisture, with high frequencies of Scopulophila indicating effectively drier conditions. Increases in the percentage of Petrophytum, characteristic of moister habitats, may indicate mesic episodes. Near-disappearance of both these species during the ensuing late Wisconsin (fig. 18) probably was caused by competition with more robust mesophytes.

While fluctuations of Scopulophila and rock spirea appear to reflect short-term changes, the longer duration decline in shadscale, accompanied first by an increase in sagebrush and horsebrush (Tetradymia sp.) and then little-leaf mountain mahogany (Cercocarpus intricatus), implies a progressive increase in effective moisture from 32,000 to 25,000 B.P. (fig. 18). The Spc-2(3) fossil assemblage, dated at 23,300 B.P., indicates a reversal in this trend. It contains higher frequencies of shadscale and fewer mesophytes than older samples.

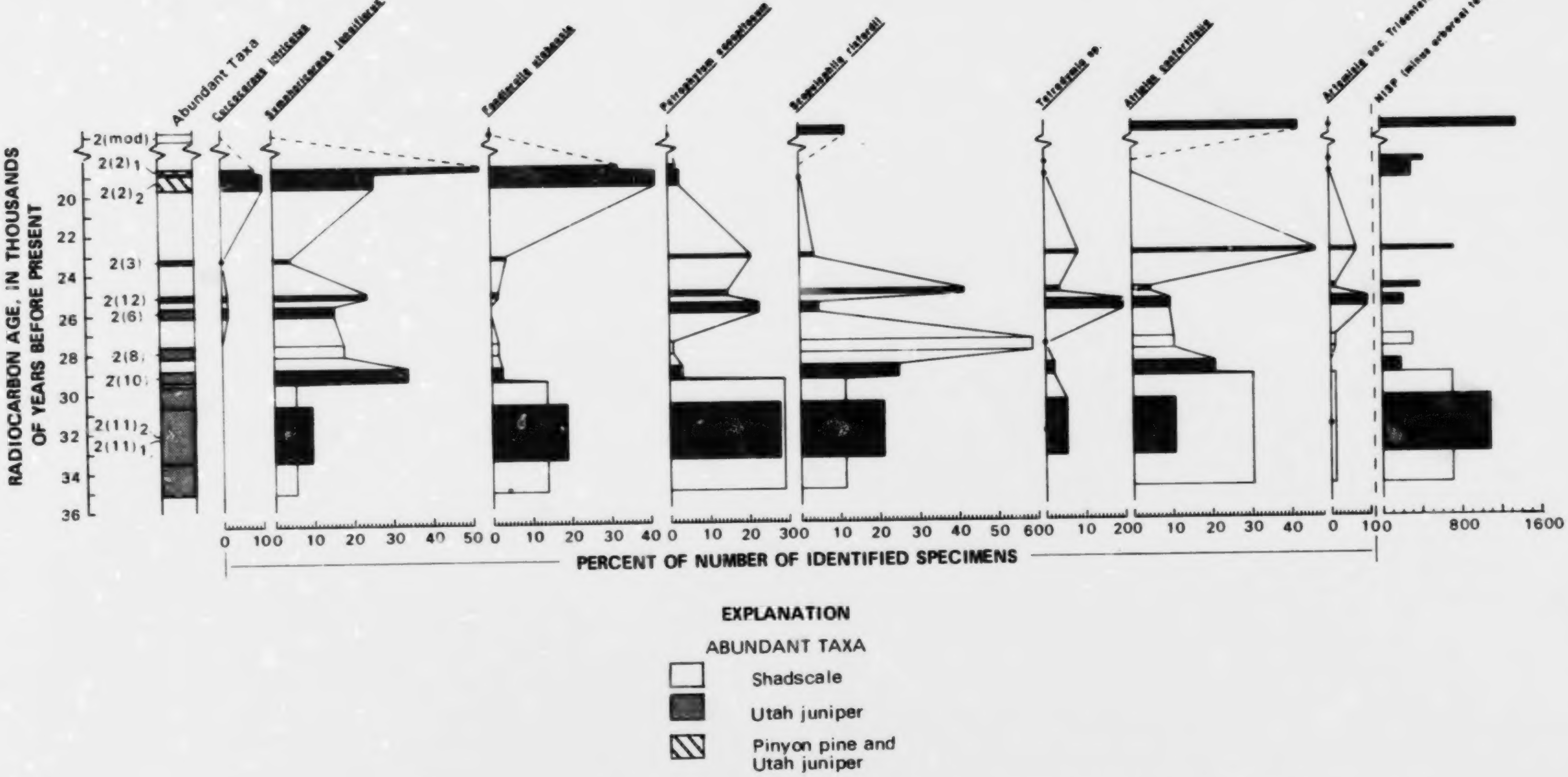


Figure 18.--Relative frequencies of selected plant taxa in macrofossil assemblages from the Specter Range-2 midden. (Vertical width of the bars is proportional to $\pm 1\sigma$ of the sample's radiocarbon date (table 6), except for the Spc-2(8) and Spc-2 (modern) samples. Open bars for samples Spc-2(8) and Spc-2(11)$_1$ denote uncertain chronologic positions; solid circle represents $\leq$ percent of number of identified specimens. See table 6 for radiocarbon dates on those samples.)

Isolated middens from elevations ranging from 790 to 1,990 m provide additional data on environments of the Nevada Test Site during the last millenia of the middle Wisconsin. The oldest are broadly correlative with the Spc-2(11) samples. At the lower end of the elevational gradient, in the Amargosa Desert, the OC-3(1) assemblage is radiocarbon-dated at about 33,000 B.P. (fig. 14; table 6). Abundant rubber rabbitbrush (Chrysothamnus nauseosus) and juniper in this midden sample indicate steppe vegetation with scattered trees. At the upper end of the altitudinal gradient, the Eyrie-5(2) assemblage, from a south-facing slope at an elevation of 1,860 m in the Sheep Range, is dated at 30,740 B.P. (figs. 13, 14). It records a xerophytic juniper woodland with pricklypear (Opuntia polyacantha), sagebrush, and little-leaf mountain mahogany (Spaulding, 1981, table 23).

Younger macrofossil assemblages, dating from 28,300 to 23,300 B.P., also yield records of juniper woodland with a diverse complement of xerophytic woodland and Great Basin Desert shrubs (Spaulding, 1981). Juniperus osteosperma was the only frequent arboreal species in this widespread woodland; pinyon pine is virtually unknown from the middle Wisconsin middens in the northern Mojave Desert. Occasional limber pine and white fir (Abies concolor) in the highest middle Wisconsin assemblage, SC-1(3) at an elevation of 1,990 m in the Sheep Range (fig. 14), indicate that this site was near the lower limit of montane conifer vegetation (Spaulding, 1981, p. 111).

Middle Wisconsin juniper-desert shrub assemblages from this region are broadly analogous to present vegetation at dry lower reaches of woodland. Contrasting estimated modern temperature and precipitation at such a site (the Eleana Range locality) with that for the Specter Range-2 site (table 5) indicates that average annual precipitation at about 30,000 B.P. was 10 to 25 percent more than at present and that mean annual temperatures were at least 3°C lower than at present. The lower woodland boundary in more arid parts of the Sheep Range lies at about an elevation of 1,980 m. Calculations based on an elevational depression of juniper of 790 m (to the Specter Range-2 site at 1,190 m) and a lapse rate of 0.5°C/100 m yield a ΔT_a value of -4.0°C. However, calculations based on an elevational depression of 1,190 m to the Owl Canyon locality (790 m) yield a $\Delta T_{\bar{a}}$ of -6.0°C.

The altitudinal zonation of vegetation in the northern Mojave Desert during the Wisconsin glacial age was unlike zonation that occurs under the present climatic regime. Utah juniper ranged from elevations less than 800 m to at least 2,000 m; xerophytic woodland and steppe shrubs were common associates over much of its 1,200 m altitudinal distribution. Arboreal species that often occur with Utah juniper at present (such as pinyon pine and ponderosa pine at higher elevations) are rarely recorded or completely missing from the fossil record. Trees most commonly associated with juniper in fossil assemblages from the higher altitude Sheep Range sites (Spaulding, 1981) are xerophytic subalpine conifers, bristlecone pine (*Pinus longaeva*) and limber pine (*Pinus flexilis*). Present extent of such plant associations in the Sheep Range is compared in figure 19 with their documented distribution in the Nevada Test Site area during the middle Wisconsin; the comparison illustrates an apparent paradox. An increase in effective moisture sufficient to permit *Juniperus osteosperma* to grow at xeric low-altitude sites like Owl Canyon should have allowed other arboreal species to become successfully established at least at elevations above 1,500 m, assuming that gradients of effective moisture were the same then as now. However, xerophytic juniper woodland occurred on moist as well as dry sites to an elevation of at least 1,750 m (figs. 14, 19); perhaps lapse rates of precipitation during the Wisconsin were different from present rates.

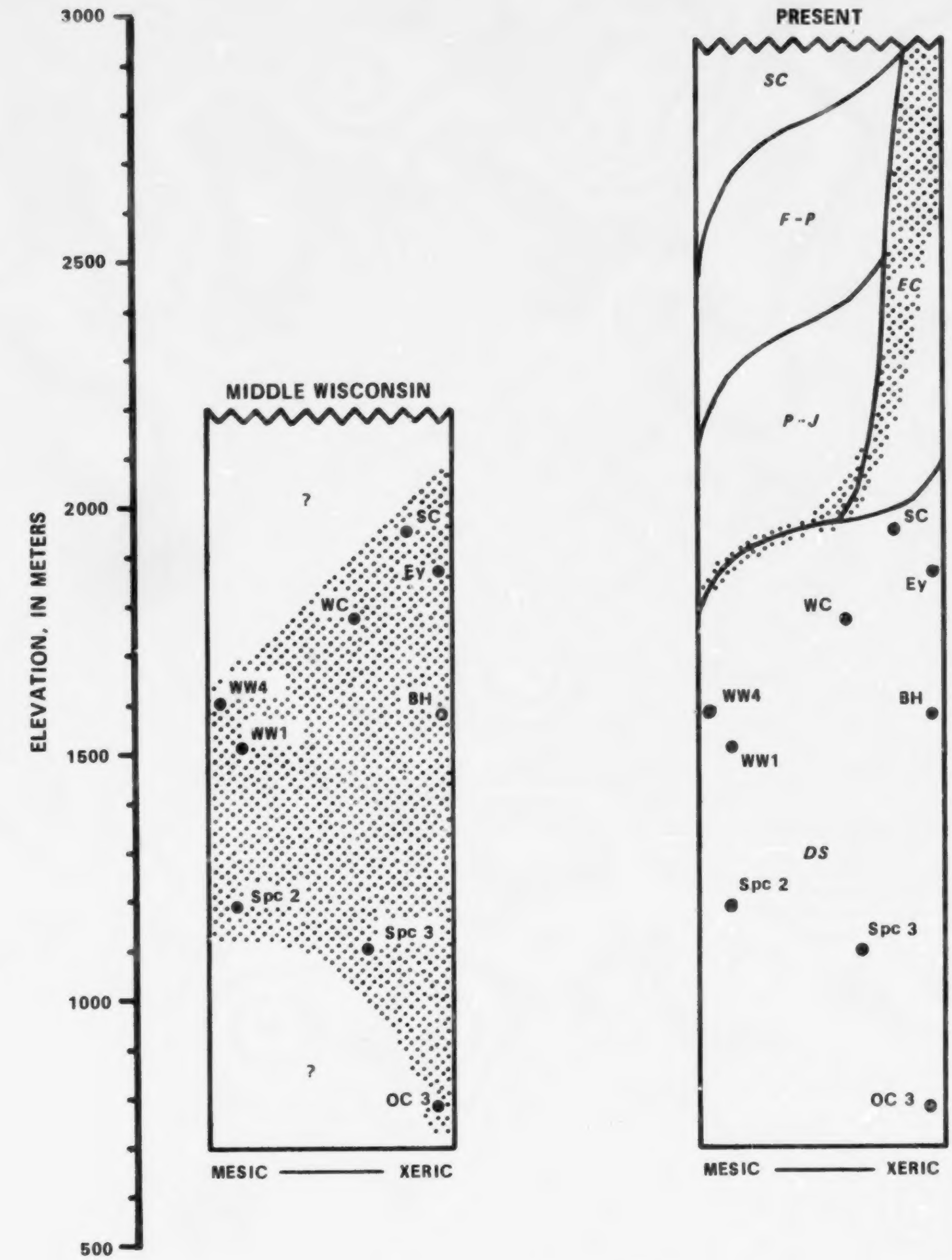


Figure 19.--Distribution of middle Wisconsin juniper-shrub macrofossil assemblages compared to the modern extent of similar associations in the Sheep Range. Abbreviations for the fossil sites are: BH, Black Hills; Ey, Eyrie; OC, Owl Canyon; SC, South Crest; Spc, Specter Range; WC, Wagon Canyon; WW, Willow Wash. Abbreviations for the modern plant-community types are: SC, subalpine-conifer woodland; F-P, white fir-ponderosa pine (Abies concolor-Pinus ponderosa) forest; EC, evergreen sclerophyll chaparral; P-J, pinyon-juniper woodland; DS, desertscrub. Stippled pattern shows distribution of similar assemblages during the middle Wisconsin and present day.

Late Wisconsin Environments

The late Wisconsin stade of North America, the last period of major continental ice-sheet expansion, is correlated with oxygen-isotope stage 2 in deep-sea cores, coeval with the late Weichselian and Devensian stades of Eurasia (Bowen, 1978; Flint, 1971). Radiocarbon analyses of subsurface sediments from Searles Lake, California, 160 km southwest of the Nevada Test Site, provide the best independent dates for the duration of this period in the Mojave Desert. The Parting Mud unit of Searles Lake encompasses the entire late Wisconsin; an average of seven radiocarbon dates on disseminated carbon from the bottom 50 cm of the unit is 23,300±1,175 B.P. (Stuiver and Smith, 1979, p. 74). Applying a correction factor of -900 radiocarbon years to this age to compensate for low radiocarbon per carbon ratios in high-bicarbonate waters (Peng and others, 1978, p. 327) yields a date of 22,600±1,175 B.P. for initiation of late Wisconsin conditions at Searles Lake. The corrected average of seven radiocarbon dates from the top of the Parting Mud (Stuiver and Smith, 1979, p. 73), marking the end of late Wisconsin conditions, is 9,600±165 B.P.

Vegetation

A date of about 22,600 B.P. for the beginning of late Wisconsin environmental conditions in the Mojave Desert is in accord with packrat-midden evidence from the Nevada Test Site. Although a gradual trend toward more mesophytic vegetation at Specter Range-2 began as early as 26,000 B.P. (fig. 18), major biotic turnover from a juniper-shadscale to pinyon-juniper woodland did not occur until after about 23,300 B.P. (sample Spc-2(3)) (table 6). Indeed, the Spc-2(3) assemblage indicates a reversal to conditions drier than those recorded by sample Spc-2(6) dated at about 25,000 B.P., and sample Spc-2(12), dated at about 26,000 B.P. (fig. 18).

The 4,000-year hiatus between sample Spc-2(3) and the late Wisconsin age Spc-2(2) assemblages (figs. 14, 18) provides only a maximum age of 23,300 B.P. for the beginning of the late Wisconsin. No middens from the Nevada Test Site yield additional samples dating to this period except Specter Range-3A. This rather poorly dated assemblage (20,200±1,800 B.P.) (table 6) yields no evidence for a major vegetation change. Samples from the South Crest midden in the Sheep Range, a xeric site at an elevation of 1,990 m (fig. 12) document a transition from juniper to subalpine-conifer woodland prior to 21,700±500 B.P. (fig. 14) (Spaulding, 1981, p. 111, fig. 27). This change, from a xerophytic juniper woodland to one apparently dominated by bristlecone pine (Pinus longaeva) and limber pine (Pinus flexilis), marks the initiation of a stadial climatic regime. Hence, packrat middens provide bracketing radiocarbon dates of 23,300 and 21,700 B.P. for the beginning of late Wisconsin climatic conditions in the vicinity of the Nevada Test Site.

The Wisconsin maximum, or full glacial, is dated at about 18,000 B.P. (CLIMAP, 1976), although local glacial maxima varied by several thousand years (Gates, 1976, p. 1138; Bowen, 1978). In the Sheep Range, there were two periods when subalpine vegetation occurred below 2,000 m; either (or both) could represent the full glacial. The first, recorded by packrat middens from the South Crest and Eyrie localities in the Sheep Range, ended by 19,000 B.P. The second, with midden evidence from the Eyrie and Deadman localities in the Sheep Range, occurred between about 18,600 and 16,800 B.P. (fig. 14) (Spaulding, 1981, fig. 27). The magnitude of the latter event appears to have been great; at the Eyrie and Deadman sites, there were changes from xerophytic vegetation characterized by Utah juniper and pricklypear cacti (Opuntia polyacantha and Opuntia phaeacantha) to subalpine vegetation dominated by limber and bristlecone pine (Spaulding, 1981, tables 23 and 24) (fig. 14).

Specter Range-2 midden samples recording a mesophytic pinyon-juniper woodland between 19,300 and 18,700 B.P. (fig. 18) do not appear to correspond to either period of lowered subalpine vegetation in the Sheep Range (fig. 14). They may conflict with evidence for extensive, xerophytic juniper woodland at higher elevations in the region. A mesophytic pinyon-juniper association at the Specter Range-2 site (an elevation of 1,190 m) contrasts with late Wisconsin-age plant fossil assemblages commonly lacking pinyon pine from elevations 1,500 to 1,970 m in the Sheep Range (fig. 14). The cause of this anomaly is not readily apparent.

The Eleana Range-2 packrat midden spans most of the last one-half of the late Wisconsin, from 17,100 to 10,600 B.P. Samples older than 13,000 B.P. document a limber-pine woodland that contrasts with both older middle Wisconsin records from the Eleana Range-3 site and present desertscrub and sparse woodland at the locality (figs. 15, 16). Changes in macrofossil frequencies toward the end of the limber-pine phase at Eleana Range-2 appear to reflect late-glacial climatic change. A trend toward effectively drier conditions is indicated by the decline of silvery-lupine (*Lupinus* cf. *argenteus*) and fern-bush (*Chamaebatiaria millefolium*), two extralocal shrubs, accompanied by increasing relative frequencies of the xerophytic shrub, dwarf-goldenweed (*Haplopappus nanus*) (fig. 20). Decreasing relative percentages of plants typical of current Great Basin steppe (*Artemisia* sec. Tridentatae; *Tetradymia* sp., *Chrysothamnus* spp.) accompany these changes. This trend may have started as early as 16,000 B.P. and appears to have been well-underway by 13,000 B.P. Variations in percentages of mountain mahogany (*Cercocarpus ledifolius*) may represent reversals, when available moisture was somewhat higher (fig. 20). These data are in general accord with the record from Searles Lake (fig. 1), indicating a change at about 16,200 B.P. (corrected date) from a lake at its maximum expansion to one undergoing dessication, with some reversals (Smith, 1979, p. 111).

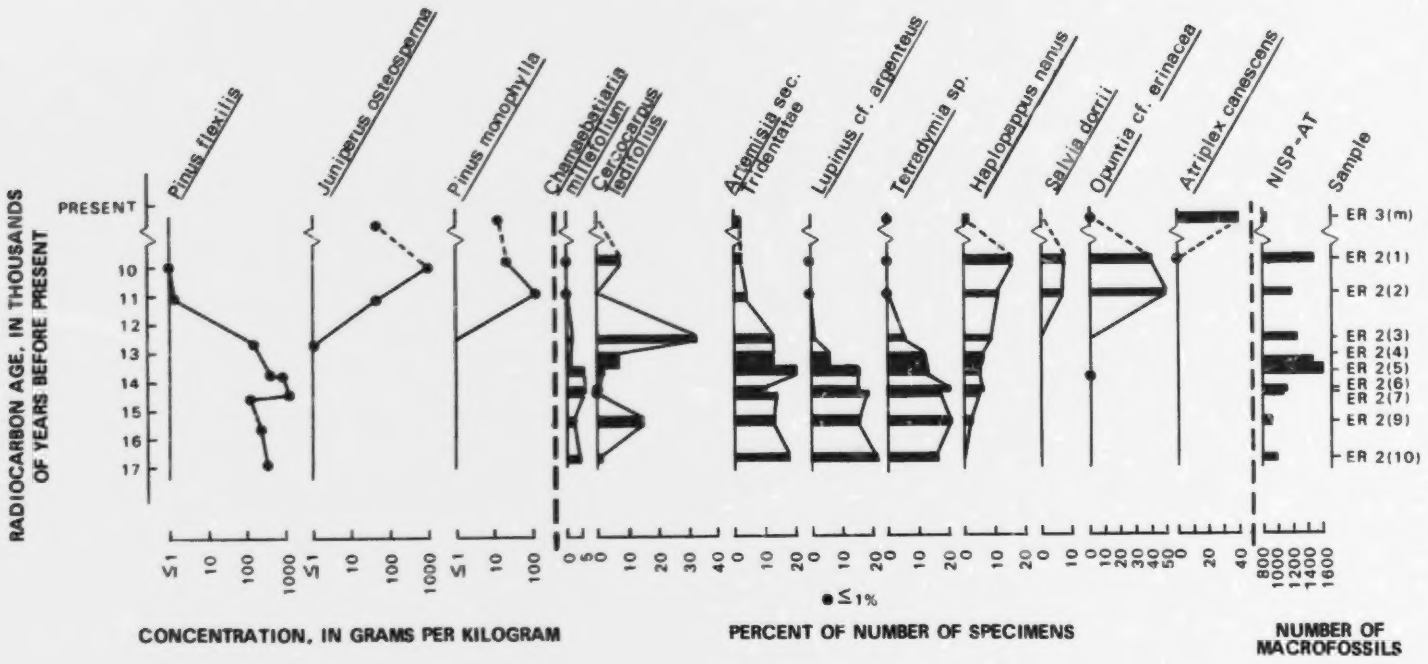


Figure 20.--Abundance of selected plant taxa in macrofossil assemblages from the Eleana Range-2 (ER-2) midden. A modern sample from the nearby Eleana Range-3 (ER-3) site is presented at the top for comparison. Concentration values for the tree species are grams of fossils of a given taxon per kilogram of sorted matrix. Abundance values of the remains of shrub and succulent species are presented as percentages of NISP-AT (number of identified specimens excluding arboreal taxa). Solid circle represents ≤1 percent of number of identified specimens.

The trend of increasingly xerophytic vegetation at Eleana Range-2 culminated in a profound change between 13,200 and 11,700 B.P. Limber pine-shrub woodland gave way to a community apparently dominated by Utah juniper, pinyon pine, and pricklypear (*Opuntia polyacantha*) (fig. 20). This transformation from a plant association with subalpine and steppe affinities to one resembling modern woodland in nearby mesic habitats signals the end of Wisconsin vegetation conditions at this site. Indices of similarity (fig. 21) show that latest Wisconsin ER-2(1) and 2(2) assemblages have many more species in common with current vegetation than do the middle Wisconsin samples from the nearby Eleana Range-3 site. Presumably this reflects a fundamental alteration of the regional climate. Climate during the terminal Wisconsin, although somewhat more mesic than the present, was quite unlike the climate of either the middle Wisconsin interstadial or most of the late Wisconsin stadial.

Climatic Regime

The record of global environmental change shows that late Wisconsin climates represent maximum departure from present interglacial conditions (CLIMAP, 1976; Bowen, 1978). A perspective on environments of this period in the vicinity of the Nevada Test Site is gained by contrasting reconstructions presented here with earlier paleoclimatic models proposed for this region.

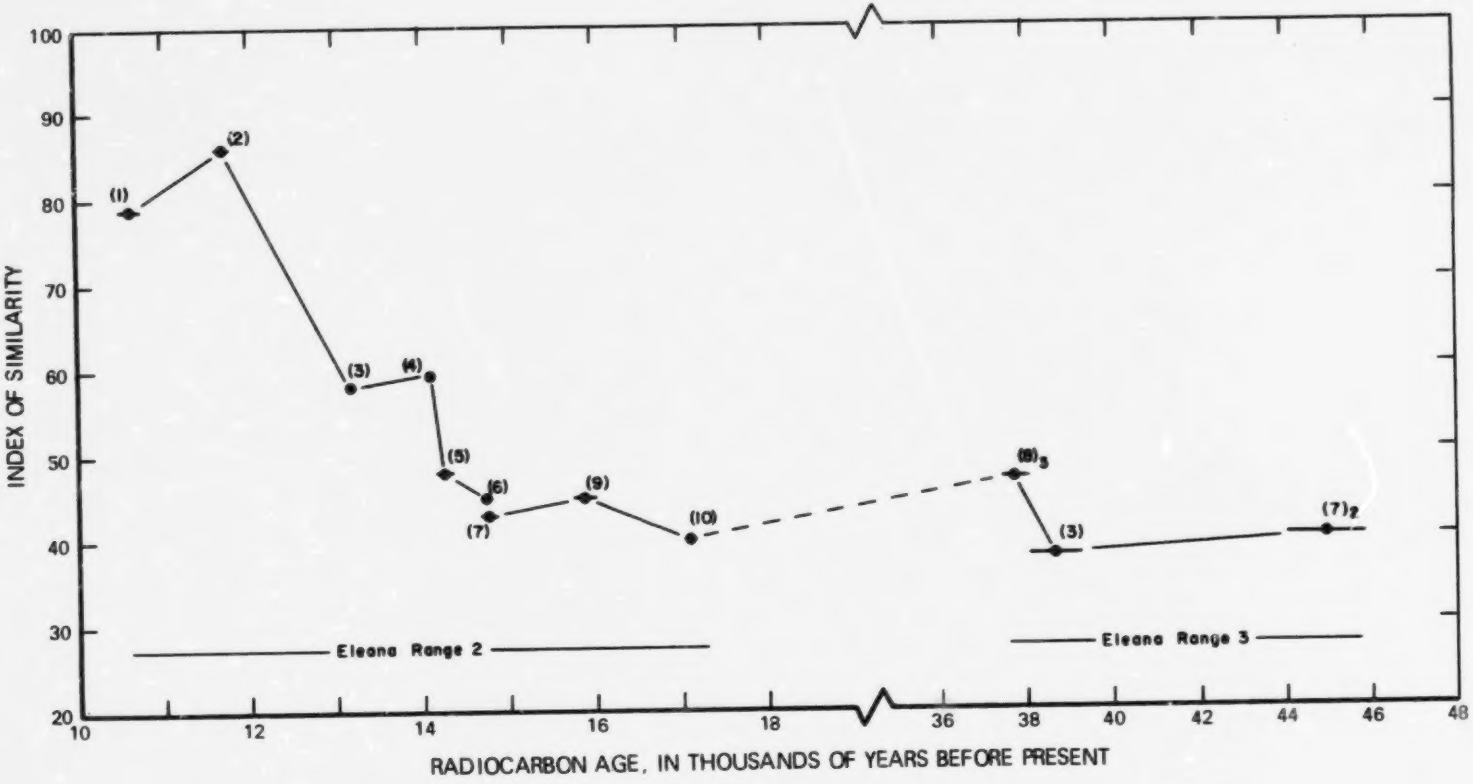


Figure 21.--Changes in similarity between Wisconsin and modern flora of the Eleana Range locality (note the break and change in the time scale; Sorensen's index of similarity is to the left). Compare the generally small indices of similarity for the late Pleistocene floras with the inferred continuity of physiognomy and structure of the vegetation (figs. 15, 16). Horizontal bars indicate ±1σ of that assemblage's radiocarbon age.

The most obvious evidence for differing ice-age climates in the Southwest are the empty basins that once contained vast freshwater lakes. In Nevada and Utah, the estimated total area of water during the late Wisconsin exceeds 89,000 km^2 (Mifflin and Wheat, 1979, p. 53-55). Antevs (1948, p. 172-174; 1952, p. 98) correlated maximum expansion of these lakes with the greatest development of continental ice sheets in the Northern Hemisphere, a hypothesis corroborated by more recent studies (Broecker and Orr, 1958; Morrison and Frye, 1965). Their expansion most often has been attributed to greatly increased annual precipitation (50 to 100 percent over current amounts), coupled with a modest decline in average annual temperatures (2.5° to 5.0°C below those of the present) (table 7). This "pluvial" model of late Wisconsin climate in the Southwest invokes equable temperatures (cool summers and mild winters), characterized by considerably more rainfall than at present (Van Devender and Spaulding, 1979; Wells, 1979). However, the implicit climatic assumptions in the term "pluvial" demand rigorous testing.

Table 7.--*Paleoclimatic reconstructions for the full-glacial period of the American Southwest*

[ΔT_a, changes in °C (degrees Celsius) in annual temperature; ΔT_s changes in °C in summer temperature; ΔT_w, changes in °C in winter temperature; ΔP, change in annual precipitation in cm (centimeters); % (percent), %P, ΔP/modern P; %E (evaporation), ΔE/modern E]

Author	Data base	Location	ΔT_a	ΔT_s	ΔT_w	ΔP	%P	%E
Antevs (1952)	Hydrologic budgets	Lake Lahontan, Nevada	-2.5 to -3.0	----	----	+8 to +16	50 to 100	-30
Antevs (1954)	Relict snowlines	North-central New Mexico	----	-5.6	----	+23	----	----
Bachhuber and McClellan (1977)	Foraminifer distributions	Lake Estancia, New Mexico	----	-9.7	----	----	----	----
Brackenridge (1978)	Relict cirques and cryogenic deposits	Montana to Arizona (lat 45°40'N to 33°20'N)	[1]-7.0	----	----	0	0	----
Broecker and Orr (1958)	Hydrologic budgets	Lake Lahontan, Nevada	-5.0	----	----	+20	80	----
Galloway (1970)	?Solifluction deposits	Sacramento Mountains, New Mexico	-10.5	----	----	-4.6	----	----
Leopold (1951)	Hydrologic budgets and snowline changes	Lake Estancia, New Mexico	-6.6	-9.0	-2.8	+18 to +25	50 to 70	-23 to -50
Mifflin and Wheat (1979)	Hydrologic budgets	Nevada, state-wide	-2.8	----	----	+8.4 to -24	[2]68	-10
Reeves (1966)	Hydrologic budgets	Llano Estacado, west Texas	-5.0	-8.0	----	+39	89	-27
Snyder and Langbein (1962)	Hydrologic budgets	Lake Spring, Nevada	[3]-5.0	[4]-7.2	----	+20	67	-30
Van Devender (1973)	Packrat middens	Western Arizona	-2.2 to -3.9	----	----	+12.3 to +22.0	----	----

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[1] Minimum estimate.

[2] State-wide average.

[3] Extrapolated by Morrison (1965); Schumm (1965); and Mifflin and Wheat (1979).

[4] Extrapolated by Schumm (1965) and Brackenridge (1978).

Reconstructions of late-glacial vegetation based on fossil-pollen analysis have provided support for the pluvial model of southwestern climate. In particular, the hypothesized existence of extensive areas of ponderosa-pine parkland and pinyon-juniper woodland were taken as evidence of mild-moist conditions (Martin and Mehringer, 1965; Mehringer, 1965, 1967). However, the macrofossil record of xerophytic vegetation in the Mojave Desert fails to verify these reconstructions (Wells and Berger, 1967, p. 1647; Spaulding, 1981, p. 207-208). More recently, Wells (1979, p. 311) has suggested that packrat-midden data also indicate an equable late Wisconsin climate, characterized by a " *** pluvial increase in precipitation over the Southwest." One aspect of late-glacial biogeography used to support this thesis is the gradient of decreasing lower limits of pinyon pine at fossil sites with declining latitude, from the Mojave to the Sonoran Deserts. In the western Sonoran Desert, *Pinus monophylla* occurred as low as an elevation of 510 m (Van Devender and Spaulding, 1979, table 1); in the northern Mojave Desert, its lowest fossil record is more than twice as high (1,190-m elevation at the Specter Range-2 site)[1], and it was uncommon below 1,550 m (Spaulding, 1976, p. 160) (fig. 14). Spaulding and others (1983) decline to accept Wells' (1979, p. 324) hypothesis that this vegetation gradient represented " *** pluvially increased summer rain *** "; instead, they propose that it was caused by the near-absence of summer rain north of about lat 36° N. A second argument advanced by Wells (1979, p. 320) to support the model of an "equable glaciopluvial" is that: "In the Mojave Desert province, the upper part of the Pleistocene woodland zone was similar to the more mesic phases of the existing pinyon-juniper woodland *** (Wells and Berger, 1967)." The only macrofossil record of mesic pinyon-juniper woodland north of lat 35° N. reported by Wells and Berger (1967, table 1) is of apparent early-Holocene age (9,450±90 B.P.) and is largely irrelevant to the discussion of late Wisconsin climates. Based on an analysis of over 30 Wisconsin-age assemblages, Spaulding (1981, p. 184) notes that pinyon pine and other mesophytic woodland plants are actually rare or missing from glacial-age woodland vegetation in the northern Mojave.

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[1] Recent (October 1983) discovery of pinyon pine (*Pinus monophylla*) in a midden from the Stripped Hills, about 10 km west of the Specter Range-2 site, establishes a lower elevational record of 1,090 m for this species in the northern Mojave Desert.

The paleoecological record from the Nevada Test Site and vicinity reveals a late Wisconsin vegetation dominated by plant species adapted to relatively cold, dry environments. There is no evidence for the presence of frost-sensitive desert plants, such as creosote bush, desert spruce, or white bursage, even at lowest elevation sites. Also, at higher elevations, there are few glacial-age fossils of plants characteristic of moist, temperate environments, such as ponderosa pine, Gambel oak, or Rocky Mountain juniper (Juniperus scopulorum). Instead, there was a zone of xerophytic pygmy conifer woodland dominated by Utah juniper and, on rare occasions, single-needle pinyon pine and juniper together, from the lowest elevation sites up to elevations of between 1,800 and 2,000 m. A zone of subalpine conifer woodland characterized by limber pine on volcanic rocks, and limber pine and bristlecone pine together on calcareous substrate, occurred above an elevation of about 2,000 m (fig. 14) (Spaulding, 1981). Great Basin Desert and steppe shrubs, such as sagebrush, horsebrush (Tetradymia sp.), and rabbitbrushes (Chrysothamnus spp.) were widespread in both types of woodland. There is no evidence for the distinct zone of mesophytic montane conifers (dominated by Pinus ponderosa, Abies concolor, and Juniperus scopulorum) that currently separates pygmy conifer from subalpine woodland (fig. 14). These macrofossil data indicate a climate quite unlike that stipulated by pluvial models.

Lower limits of woodland plant species were depressed during the Wisconsin, although the amount of elevational displacement varied among different taxa (fig. 22). Minimum-displacement estimates for the two conifers most common in the late Wisconsin vegetation of southern Nevada, limber pine and Utah juniper, are among the greatest estimates; both occurred more than 1,000 m below their current lower limits. If it is assumed that the lower limit of these two species is determined by evapotranspirational stress caused by high summer temperatures, lapse-rate calculations can be used to derive estimates of full-glacial summer temperature declines (ΔT_s). Studies by Major (1977, p. 65) of present-day temperature regimes in arid and semi-arid mountains of California indicate summer lapse rates of -0.6 to -0.75°C/100 m. Applying these rates to displacement values for juniper and limber pine yields minimum estimates of ΔT_s of about -6° to -9°C (table 8). The range of overlap of values for the two species is from about -7°C to -8°C.

Relative decline of full-glacial winter temperatures (ΔT_w) is a critical parameter in these reconstructions. A modest ΔT_w of, say, -3.0°C would indicate an equable temperature regime with a low annual range of variation and a modest estimate of mean annual temperature decline. However, the marked lack of thermophilous plant species in even lowest elevation middens provides a strong argument against a conservative estimate of ΔT_w. An example is creosote bush, which, according to Beatley (1974, table 1), is excluded from sites with mean minimum temperatures lower than -1.4°C, and sites with extreme minimum temperatures below -16.8°C (table 9). Because a ΔT_w of less than -6.0°C would leave some low-elevation sites in the region with mean minima above -1.4°C (as measured by Beatley's method) and not exclude *Larrea divaricata* from the study area, full-glacial decline in winter temperatures must have exceeded that value (table 9).

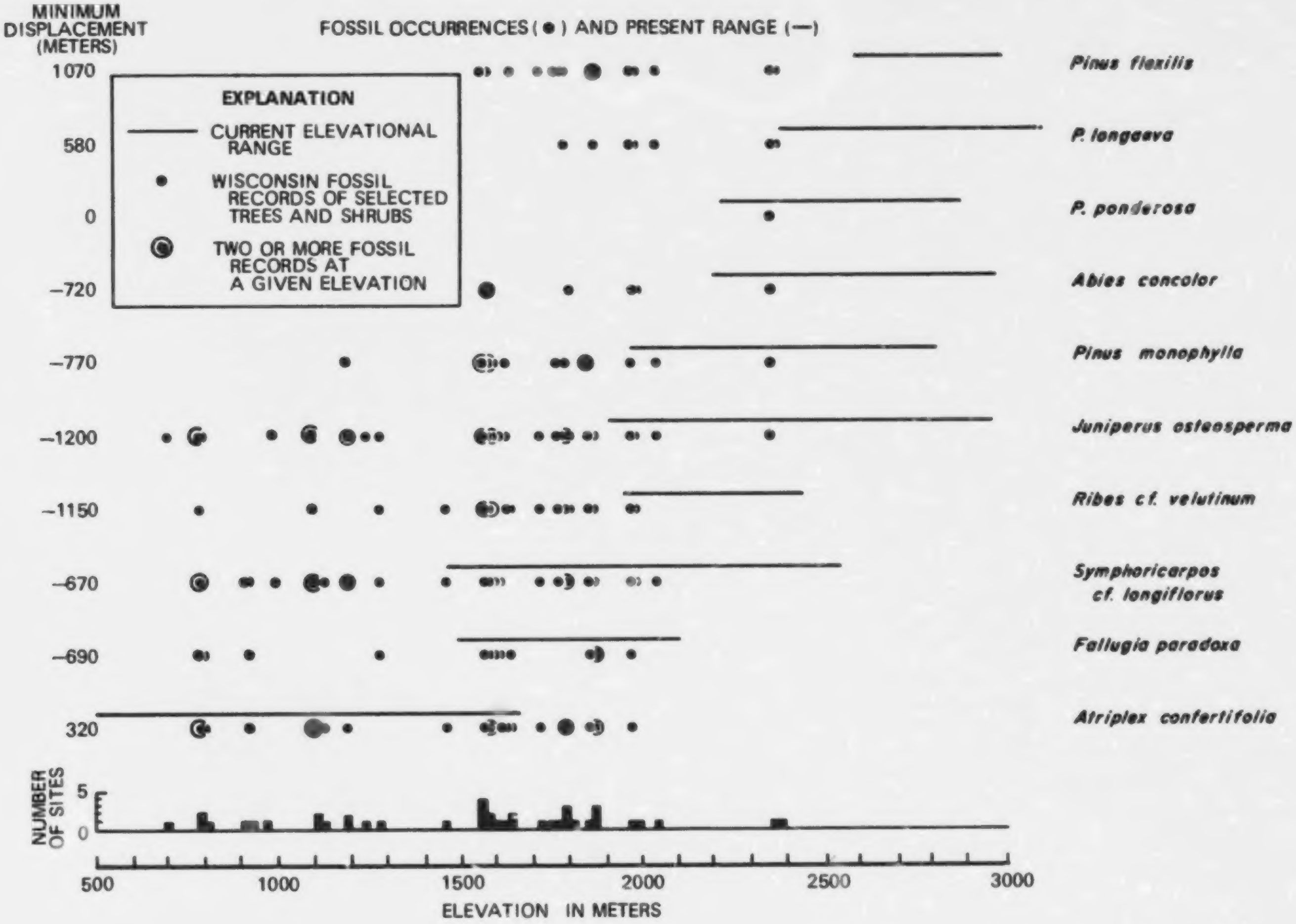

Figure 22.--Current elevational range and Wisconsin fossil records of selected trees and shrubs; estimates of minimum displacement are to the left and (except for *Atriplex confertifolia*) are the elevation of a species' lowest fossil record subtracted from the elevation of its present lowest occurrence. All sites are north of lat 36°20' N. and south of lat 37° N., west of long 115° W. and east of long 117° W., on calcareous substrate only.

Table 8.--*Estimates of minimum displacement of Utah juniper and limber pine and resultant calculations of the full-glacial decline in summer temperatures for southern Nevada*

[Lowest elevation fossil record for Juniperus osteosperma is from Mehringer (1967); lowest record for Pinus flexilis is from Spaulding (1981). ΔT_s, relative decline in full-glacial summer temperatures; °C, degrees Celsius; m, meter]

Species	Lowest fossil site; elevation	Present lower limit	Minimum displacement
Juniperus osteosperma	Tule Springs, Las Vegas Valley; 700 m	1,900 m	1,200 m
Pinus flexilis	Willow Wash-4, Sheep Range; 1,585 m	2,650 m	1,065 m

Lapse rate calculations of ΔT_s

Lapse rate[1] (C°/100 m)	Minimum displacement	ΔT_s
-0.60	1,200 m	-7.2°C
- .70	1,200 m	-8.4°C
- .75	1,200 m	-9.0°C
- .60	1,065 m	-6.4°C
- .70	1,065 m	-7.5°C
- .75	1,065 m	-8.0°C

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[1] Values from Major (1977).

Table 9.--*Range of minimum temperature values at 39 sites presently supporting creosote bush (Larrea divaricata), and estimates of the minimum decline in late Wisconsin winter temperatures necessary to exclude that species from all sites*

[ΔT_w, postulated minimum relative decline in full-glacial winter temperature; °C, degrees Celsius; data are from Beatley (1974, table 1)]

MEAN MINIMUM TEMPERATURES		
Lowest value (A)	Highest value (B)	ΔT_w (A-B)
-1.4°C (site 34)	4.5°C (site 5)	-5.9°C
MEAN OF EXTREME MINIMUM TEMPERATURES		
Lowest value (A)	Highest value (B)	ΔT_w (A-B)
-16.8°C (site 34)	-10.8°C (site 15)	-6.0°C

Shadscale (Atriplex confertifolia) was widespread in the late Wisconsin juniper woodlands of southern Nevada. It occurred at higher elevations than it does today, probably in response to the absence of potential competitors that appear to determine its present upper limits (Spaulding, 1981, p. 205). There is little fossil evidence for desertscrub species that occur at intermediate elevations above shadscale today, and the glacial-age juniper woodland seems to have been less diverse than present vegetation at the fossil sites (Spaulding, 1981, p. 194-199). This apparent decrease in floristic diversity is attributed to winter temperatures lower than those indicated by models of equable late-glacial climates. Expansion of shadscale, today typical of the most frigid desert habitats in the vicinity of the Nevada Test Site (Beatley, 1974, 1975), provides strong qualitative support for a relatively large decline in late Wisconsin winter temperatures and a fairly arid precipitation regime.

Averaging these minimum estimates of ΔT_s and ΔT_w yields a minimum value of about -7°C for the decline of mean annual temperature (ΔT_a) during the late Wisconsin. Subtracting this estimate of ΔT_a from the current mean annual temperature at the lowest elevation fossil locality, Owl Canyon at 795 m, yields a range of temperature values (10° to 11°C) characteristic of the lower reaches of modern woodland in the region (table 5). This is in agreement with glacial-age macrofossil assemblages from low-elevation sites dominated by dry-woodland and cold-desert plants.

Reconstruction of the late Wisconsin precipitation regime of the Nevada Test Site and vicinity begins with estimates of seasonality. The late-glacial flora indicates a pronounced absence of summer rain. The abundance of Great Basin Desert taxa and scarcity of plants that today appear to require at least some summer moisture (such as *Quercus* spp., *Coleogyne ramosissima*) indicates the contribution of warm-season rainfall was less than 10 percent of the annual total. This is not unexpected because, during a glacial climatic regime, lowered temperatures would tend to suppress development of subtropical high-pressure systems presently responsible for winds that bring summer rains to the monsoonal Southwest (Van Devender and Wiseman, 1977) and impede development of surface low-pressure systems that draw maritime air northward from the Gulf of California (Huning, 1978, p. 80).

The late Wisconsin flora of the northern Mojave Desert provide no evidence for the drastic relative increase in annual precipitation (in excess of 50 percent above present values) proposed by some authors (table 7). At this point, general analogs seem to provide the best approach for deriving estimates of full-glacial precipitation. In the White Mountains of California (fig. 1), average annual precipitation (P_a) near the lower limit of subalpine (limber pine) woodland (at about 2,800 m) (Mooney and others, 1962, fig. 4) is calculated to be about 300 mm, based on a value of 350 mm/yr^{-1} at the Crooked Creek Research Station (at an elevation of 3,096 m) (La Marche, 1973, p. 635), and a local precipitation lapse rate of 17 mm/100 m (Major, 1977, p. 66). Assuming this value (300 mm) approximates average annual precipitation during the full glacial at the Eleana Range locality, the estimated relative increase of P_a is 33 to 39 percent above today's amounts (table 5). This modest increase is supported by two tree-ring chronologies from the Eleana Range-2 packrat midden (fig. 23). Annual-ring widths of these two radiocarbon-dated limber-pine specimens are extremely small, averaging less than 0.2 mm. It is unlikely that such sensitive tree rings would have been produced except by trees under appreciable stress. Estimates of relative increase in precipitation of less than 40 percent also are consistent with the full-glacial record of pinyon-juniper woodland at the Specter Range-2 site. A 30 to 40 percent increase over today's amounts (table 5) would result in values estimated to be between 226 and 265 mm/yr^{-1}. Present precipitation at Ely, Nevada, which lies at the lower limit of pinyon-juniper woodland, is 221 to 245 mm/yr^{-1} (table 4).

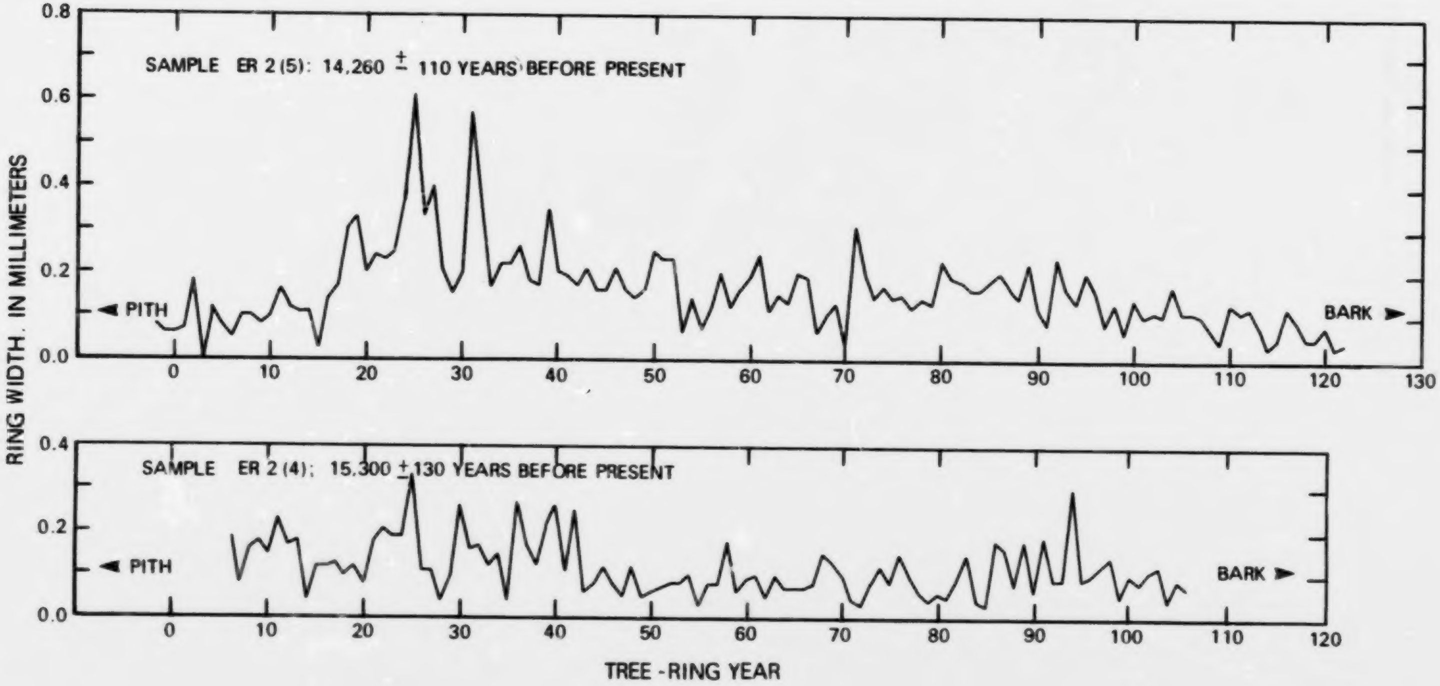


Figure 23.--Tree-ring chronologies from two limber-pine specimens from the Eleana Range-2 (ER-2) midden. (The radiocarbon date for each specimen also is shown; table 6.) The specimens are tied neither to a calendar year nor to the relative age of the tree and the time scale at the bottom is for illustrative purposes only. Cross-dating is not implied by the superposition of those two chronologies. Analysis by Harriet Garfinkel, College of Forest Resources, University of Washington.

The Transition Period

Several authors (Wright, 1976; Davis, 1981; Watts, 1980) have emphasized the time-transgressive nature of vegetation change at the end of the last glacial age in other parts of the continent; this also appears to have been the case in the Mojave Desert. Contrary to the assertion of Van Devender and Spaulding (1979, p. 709), the packrat-midden record provides no evidence for contemporaneous vegetation change at all sites at about 11,000 years ago (Spaulding, 1983, p. 256). Because synchroneity of vegetation change is not evident, there is a need for arbitrary time lines. The conventional dates of 10,000 B.P. for the end of the Wisconsin and 8,000 B.P. for the end of the early Holocene are adopted here.

Major Vegetation Changes

The latest Wisconsin (12,000 to 10,000 B.P.) vegetation at the Eleana Range-2 site was dominated by plants that presently occur nearby although a greater variety of mesophytes occurred, including some full-glacial relicts. The abundance of pinyon pine and Utah juniper in ER-2(2) and 2(1) also indicates a denser vegetation than exists at the site today. Progressive desertification after about 11,000 B.P. caused opening of the pinyon-juniper woodland and final extirpation of such extralocals as limber pine and curl-leaf mountain mahogany.

Development of postglacial woodland at the Eleana Range occurred between about 13,200 and 11,700 B.P. This is surprisingly early, relative to the date of about 11,000 B.P. for the end of Wisconsin vegetation conditions throughout the Southwest suggested by Van Devender and Spaulding (1979, p. 706). However, the Eleana Range record agrees with many glacial, oxygen-isotope, and pollen chronologies that show impact of increasing northern-hemispheric temperatures by at least 12,000 B.P. (Dansgaard and others, 1971; Porter, 1971; Barnosky, 1981; Mehringer, 1967). The maximum of northern hemisphere summer insolation was reached by about 11,000 B.P. (Broecker and van Donk, 1970, fig. 10; Ruddiman and McIntyre, 1981, fig. 2). Thus, an early date for the response of vegetation at the Eleana Range-2 site to a warming climate is not unexpected, particularly if species such as limber pine were near the limits of their environmental tolerance here during late Wisconsin time.

An early change to postglacial vegetation conditions also took place at low elevations on the periphery of the Amargosa Desert. The Point of Rocks midden records (at elevations ranging from 900 to 930 m) indicate that, at least at some sites, woodland gave way to desertscrub prior to 14,800 B.P. The surprisingly early dates for desert vegetation at the Point of Rocks-3 site (14,800 B.P.) and at the Point of Rocks-1 site (11,800 B.P.), indicates that woodland vegetation was not continuous below an elevation of about 1,000 m after about 15,000 years ago (Spaulding, 1983). Instead, low elevations in the vicinity of the Nevada Test Site may have supported a mosaic of woodland, occupying mesic habitats, and desertscrub on xeric sites.

In contrast to the early records of shrub vegetation in the lowlands, middens from higher elevation desert sites show that juniper woodland persisted as late as 9,400 B.P. in the Sheep Range (Spaulding, 1981, p. 191) and 7,800 B.P. in the Spotted Range (Wells and Berger, 1967, table 1). These localities were in the upper part of the late Wisconsin zone of pygmy-conifer woodland (above an elevation of 1,200 m) (fig. 14). Effective moisture was sufficient at such higher altitudes to maintain xerophytic woodland species after they had been extirpated from the lowlands.

An insight into the dynamics of vegetation change at the end of the glacial age is provided by contrasting similarity indices for midden samples from Owl Canyon and the Eleana Range. Macrofossil assemblages from the Owl Canyon-2 midden document vegetation conditions after juniper woodland gave way to desertscrub, and the two youngest assemblages from Eleana Range-2, after limber pine gave way to pinyon-juniper woodland. However, similarity coefficients between Owl Canyon-2 assemblages and the present vegetation at the Owl Canyon-2 site are less than 10, while those comparing ER-2(1) and 2(2) samples to the modern vegetation exceed 70 (see Supplemental Data section) (fig. 21). The Eleana Range locality was near the upper limit of late Wisconsin pygmy-conifer woodland (fig. 14); plants such as juniper, pinyon pine, and pricklypear reached the Eleana Range-2 site soon after the triggering climatic change. However, thermophilous shrubs that typify present vegetation at Owl Canyon (such as creosote bush, desert spruce, and white bursage) were apparently absent from the region during the late Wisconsin. The dissimilarity between the latest Wisconsin and modern flora at Owl Canyon is thus ascribed, in large part, to lag time in northward migration of warm-desert shrubs.

The major vegetation change in the region at the end of the last glacial age, from subalpine-conifer to pinyon-juniper woodland and, at lower elevations, from pygmy-conifer woodland to desertscrub, occurred at different times at different sites (fig. 14). An important variable that affected the timing of major vegetation change, exclusive of the timing of the forcing climatic change, was the position of the fossil site relative to the environmental tolerance of species growing there. Middens from xeric sites near the lower limit of a given vegetation zone (such as Owl Canyon, Point of Rocks, or the Eleana Range) record relatively early response to postglacial warming. Records from mesic sites, and from higher elevations within a given vegetation zone, are not as sensitive and document less vegetation response until the climate change had progressed quite far.

Desert vegetation took at least 6,000 years to spread over most of its present elevational range (fig. 14). In the northern Mojave, the transformation from woodland to desertscrub was nearly complete by about 9,000 B.P. These findings diverge from the model proposed by Van Devender (1977b, p. 190-191; Van Devender and Spaulding, 1979, p. 708) indicating that widespread woodland persisted throughout the early Holocene in most of the Mojave Desert, abruptly giving way to desertscrub at about 8,000 B.P. Early Holocene woodlands probably were more widespread farther south in the current Sonoran Desert.

Both final desiccation of the vast inland lakes of the Great Basin and ultimate demise of woodland vegetation in desert lowlands occurred between 10,000 and 8,000 years ago. At Searles Lake, desiccation was complete by about 9,600 B.P., the end of a period of declining lake levels that, with one major reversal, began as early as 16,200 B.P. (Smith, 1979, fig. 41; Peng and others, 1978, p. 325). In the vicinity of the Nevada Test Site, anomalous desertscrub vegetation had replaced woodland at most sites below an elevation of 1,600 m by about 9,000 B.P. (fig. 14). Anomalous desertscrub is a general term applied to past plant associations characterized by extralocal shrubs and succulents that also lack important elements of modern vegetation. Late Wisconsin and early Holocene middens from the periphery of the Amargosa Desert, and the Eureka Valley, document such vegetation (fig. 14). Most shrub species abundant in the Point of Rocks, Owl Canyon-2, and Last Chance Range midden assemblages (at elevations between 800 to 960 m) typify present vegetation at elevations between 1,400 and 2,000 m.

It is not known when anomalous desertscrub vegetation gave way to plant communities characteristic of the present vegetation at the Amargosa Desert sites. At the Eureka Valley locality, 160 km to the northwest, final development of current plant associations was delayed until after 5,000 B.P. (fig. 24). The lag in this development, from the time of extirpation of woodland to establishment of desertscrub vegetation similar to today's, resulted in part from the time it took for warm-desert species to migrate northward. Expansion of these shrubs to more northerly latitudes probably began before 10,000 B.P.; middens from the Amargosa Desert provide the earliest evidence for their arrival in the vicinity of the Nevada Test Site. Assemblages from Point of Rocks-1 and 2 sites, dating between 10,000 and 9,000 B.P., are the oldest to contain such xerophytes as creosote bush (Larrea divaricata) and chaff-bush (Amphipappus fremontii). Creosote bush does not appear in the Eureka Valley record until about 5,500 B.P., and chaff-bush does not appear until 1,500 B.P. (fig. 24). Prior claims for the presence of creosote bush of Wisconsin age in the northern Mojave Desert (Spaulding, 1976, p. 160; 1980, p. 89) must await confirmation by radiocarbon dates run directly on those fossil remains. Until such tests are made, these earlier records must be considered dubious; they are not replicated in this study. Migration lags were an important aspect of postglacial vegetation development in the eastern United States (Davis, 1981; Watts, 1980) and, despite previous statements to the contrary (Van Devender and Spaulding, 1979, p. 710), appear to have played an equally important role in the transition to modern vegetation in the Southwest.

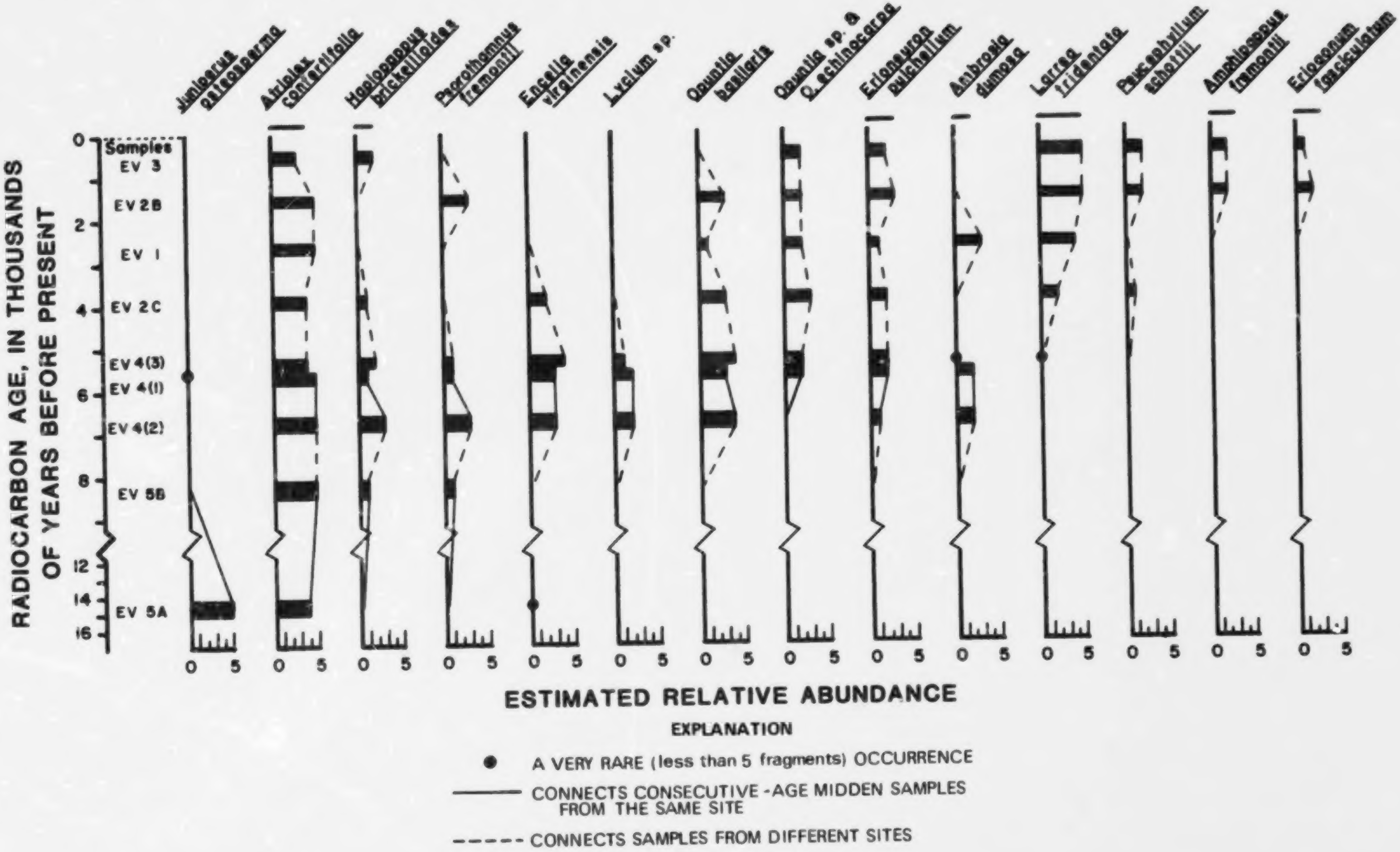


Figure 24.--A time series of packrat-midden samples from the Eureka View locality, northern Eureka Valley, Inyo County, California; estimated abundance of the species in the present vegetation is presented at the top for comparison; width of bars is equal to ±1σ of that sample's radiocarbon age (note break and change in time scale). EV, Eureka View; subjectively assigned relative abundance values are: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare.

Climates of the Transition Period

The latest Wisconsin and early Holocene vegetation of most of the Mojave Desert was xerophytic, relative to that at comparable sites in the Sonoran Desert. Desertscrub communities appear to have developed earlier in the Mojave. The oldest record of shrub-dominated vegetation in the vicinity of the Nevada Test Site exceeds 14,500 years. In the southern Mojave Desert, evidence for the early inception (by at least 10,500 B.P.) of desertscrub comes from middens in the Marble Mountains, 230 km south of the Nevada Test Site (Spaulding, 1980). The elevation of these early desert-vegetation records in the Mojave Desert varies from 465 m in the Marble Mountains to 960 m in the Last Chance Range of Nevada. At the same time (11,500 to 9,000 B.P.), juniper woodland occurred at least as low as 520-m elevation in the Whipple Mountains of the western Sonoran Desert, 310 km south-southeast of the Nevada Test Site in the Colorado River Valley. Mead and others (1978, p. 185-186; Van Devender, 1977b) report that radiocarbon dates on these woodland assemblages are as young as 8,900 B.P. Other sites in western Arizona that confirm the presence of low-elevation woodland in the Sonoran Desert include those from the Artillery and New Water Mountains (Van Devender, 1973, table 3). Closer to the Nevada Test Site, in the extreme eastern part of the Mojave Desert, juniper woodland extended to at least an elevation of 560 m in the lower Grand Canyon (fig. 1). This early Holocene woodland was rich in shrub and succulent species; radiocarbon dates on these assemblages are as young as 8,900 B.P. (Phillips, 1977, table 1).

The early development of desertscrub vegetation in the Mojave Desert and persistence of woodland in the Sonoran Desert and Grand Canyon, appears to have been a function of differing precipitation regimes. The cline of increasingly xerophytic vegetation from southeast to northwest parallels the existing gradient of warm-season precipitation from the summer-wet (monsoonal) Sonoran Desert to the summer-dry Mojave Desert. Thus, the dichotomy between paleovegetation of the two regions during the latest Wisconsin and early Holocene was probably also due to differences in the relative amount of summer rainfall. This author suggests that, beginning by 14,000 B.P., increasing summer temperatures led to a marked increase in summer, and perhaps autumn, precipitation in the present monsoonal Southwest (Sonoran and Chihuahuan Deserts). Transition period woodlands in these areas were probably maintained at low elevations by relatively high levels of effective moisture during the growing season. The Mojave Desert is farther removed from the sources of warm-season precipitation and may have been beyond the limits of major influence of this phenomenon. Desertscrub vegetation developed earlier in the Mojave Desert because there was inadequate precipitation to compensate for increasing warm-season moisture deficits.

Between 12,000 and 8,000 years ago, the obliquity of the Earth was such that summer was a time of more intense insolation than it is today, and winters were less well-heated than at present (Bryson and Swain, 1981, p. 143-144; Kutzbach, 1981, p. 59). Peaks in northern-hemispheric summer insolation and seasonal contrast may have resulted in 20 to 100 percent more summer rainfall than at present in some monsoonal regions (Kutzbach and Otto-Bleisner, 1982; Bryson and Swain, 1981, table 2). Midden localities that document woodland vegetation in the desert West at this time, such as the lower Grand Canyon and the Whipple Mountains, are south and east of the Nevada Test Site and are closer to sources of tropical maritime air--the Gulfs of California and Mexico. The early postglacial woodland of the monsoonal Southwest probably did not result from persistence of the glacial-age precipitation regime, as suggested by Van Devender (1977b, p. 192). Rather, juniper and other xerophytic woodland species may have been maintained at lower elevations than they occur at present by enhanced summer rainfall. Although there was probably a relative increase in summer rainfall over today's meager amounts in the Mojave Desert, it was insufficient to maintain woodland at low elevations.

At about 10,000 years ago, summer and fall precipitation in the vicinity of the Nevada Test Site may have exceeded present amounts by as much as 50 percent. This inference is based on the distribution pattern of woodland across the Southwest and the timing of its disappearance in different areas. Plant species indicative of increased summer rainfall became more important in the Nevada Test Site midden record between 12,000 and 10,000 years ago. The abundance of *Agave utahensis* and cacti in the Owl Canyon-2 and Point of Rocks-2 assemblages is consistent with a thesis of increased warm-season precipitation during the Wisconsin to Holocene transition. In the Searles Lake area, the apparent latest Wisconsin expansion of shrub live-oak (*Quercus turbinella*) (Spaulding and others, 1983) may be evidence of increased summer rain. The interior race of this species is presently restricted to mountains of the monsoonal Southwest (Little, 1976, map 147). There may have been insufficient time for many other summer-rain dependent species to migrate into the area. Most appear to have been absent from the Southwest during the late Wisconsin (Van Devender and Spaulding, 1979, p. 708), and it may have taken them thousands of years to reach the borders of the present-day Mojave Desert.

The source of warm-season precipitation during the latest Wisconsin and early Holocene presumably was to the south in the Gulf of California and Pacific Ocean, or to the southeast in the Gulf of Mexico. Tropical storms of August through October that presently move up the trough of the Colorado River Valley may have been more common than they are today. There is no immediate evidence for a relative increase in precipitation over current values during the winter half-year, although effective moisture during the winter probably was greater than today. While summer temperatures are inferred to have been as much as 1° to 2°C higher than today, winter temperatures may have been 1°C lower than today. This is based on the observation that seasonal contrasts were unusually large in the northern hemisphere between 11,000 and 9,000 B.P. (Broecker and van Donk, 1970, p. 190; Bryson and Swain, 1981, p. 143; Kutzbach and Otto-Bleisner, 1982).

The Last 8,000 Years

It generally is agreed that the middle Holocene was a time of increased northern-hemispheric temperatures (Deevey and Flint, 1957). However, estimates of the duration of this period of warm temperatures, and timing of the thermal maximum, differ from region to region. It appears that the period of maximum temperatures during the Holocene was time-transgressive (Wright, 1976, p. 594). As with previous portions of this report, this climatic event is considered within the context of a time-stratigraphic unit, the middle Holocene. The date chosen for the beginning of the middle Holocene, 8,000 years ago, is close to the time of final demise of woodland in high desert habitats of the northern Mojave Desert (fig. 14) (Wells and Berger, 1967, table 1), as well as its decline throughout wide areas in the present Sonoran Desert (Van Devender, 1977b).

Middle Holocene Climatic Variations

Pollen-stratigraphic data from north-central and northwestern North America are in general agreement with the Mojave Desert record. All show that the transition to postglacial vegetation conditions was complete by, at the latest, 9,000 B.P. (Barnosky, 1981; Webb and Bryson, 1972; Heusser, 1977; Wright, 1976). The apparent conflict with evidence for delayed development of desert vegetation in the Sonoran and Chihuahuan deserts (Van Devender, 1977b; Van Devender and Wiseman, 1977, p. 21) is probably due to more summer precipitation in these areas. Final extirpation of extralocals such as juniper in the lowlands of the monsoonal Southwest was delayed until the end of the early Holocene, when increased summer precipitation no longer compensated for warm-season moisture stress.

Martin (1963, p. 61) was among the first to suggest that the middle Holocene was a time of increased effective moisture, based on pollen data from southeastern Arizona. While little confirmation of an initial, early Holocene (10,500 to 8,000 B.P.) arid period is available (Van Devender, 1977b), Martin's hypothesis that there was enhanced summer rainfall between about 8,000 and 4,000 B.P. has been strengthened by additional studies in the Chihuahuan Desert (Mehringer and others, 1967; Van Devender and Wiseman, 1977; Van Devender and Worthington, 1977). Lacustrine evidence indicates that this also was the case in the Mojave Desert, although the relative amount of summer rain probably was less. The hypsithermal-age saline lake in the Searles Basin (fig. 1) attained a depth of up to 45 m above the present playa surface. It may have been caused by a relative increase in frequency and amount of summer rain, although it is unknown why it was dry during the preceding early Holocene. An uncorrected radiocarbon date on wood from the Overburden Mud laid down by this saline lake is 3,520±190 B.P.; an uncorrected radiocarbon date on disseminated organic carbon is 6,630±390 B.P. (Smith, 1979, p. 112, fig. 30).

Variations in the lower limit of pinyon-juniper woodland in the Sheep Range (fig. 1) also indicate increased effective moisture during the middle Holocene. Two middens from sites in current desert, about 150 m below the woodland boundary, contain abundant Utah juniper and common pinyon pine and are dated at 5,210±95 (the Desert View site) and 3,520±100 B.P. (the Basin Wash site) (fig. 14) (Spaulding, 1981, p. 209). Additional evidence for a moist hypsithermal in the vicinity of the Nevada Test Site includes the presence of extralocal pricklypears (*Opuntia polyacantha* and *Opuntia phaeacantha*) in the Desert View midden, as well as the mesophytes longleaf brickellia (*Bricklellia* cf. *longifolia*) and desert-willow (*Chilopsis linearis*) in the desertscrub assemblage from the Willow Wash-2 site in the Sheep Range (4,125±90 B.P.) (Spaulding, 1981, table 11).

As mentioned previously, it appears the middle Holocene also was a time of higher temperatures. Isolated middens from the Sheep Range, dating from about 4,130 to 3,240 B.P., yield evidence for warmer winters. The record of desert-willow in the Willow Wash-2 midden is pertinent because the species is frost-sensitive and is restricted from such protected, cool sites today, even when there is adequate moisture. Warmer winter minima may be indicated by the presence of blue yucca (Yucca baccata) in the CT-1(1) (3,310±100 B.P.) and Spires-1 middens (3,240±100 B.P.) (fig. 14); both sites presently lie more than 70 m above its upper limit (Spaulding, 1981, p. 136).

Northward migration of warm-desert shrubs continued through the middle Holocene. On xeric south slopes in the Eureka Valley (fig. 1), anomalous desertscrub characterized by shadscale, rayless brittlebush (Encelia virginensis), and cactus (Opuntia spp.) gave way to shadscale-creosote bush vegetation between 3,900 and 2,600 B.P. (fig. 24). While the unusual aspect of mid-postglacial plant communities at the Eureka View locality resulted in part from delayed immigration of thermophiles, many species that occurred on these xeric dolomite slopes during the middle Holocene are now restricted to more mesic habitats.

La Marche's (1973) dendrochronologic reconstruction of climate variation in the White Mountains of California, 35 km northwest of the Eureka Valley (fig. 1), provides an independent data base for the middle and late Holocene. The remains of bristlecone pine (Pinus longaeva) trees occur far above present treeline there, which is rather firm evidence of fluctuations in its upper limit caused by long-term temperature changes. A period of relatively high temperatures is inferred from the start of the record at about 7,400 B.P. to between about 3,500 to 3,000 B.P. La Marche (1973, p. 655) suggests that subsequent late Holocene lowering of treeline was caused chiefly by a decline in warm-season temperatures. For the purposes of this study, a date of 3,000 B.P. for the end of the middle Holocene is accepted.

Late Holocene Fluctuations

Although records of vegetation change over the last 3,000 years are plentiful, they usually reflect environmental changes of a lower magnitude than most of those discussed previously. Many late Holocene assemblages indicate increased effective moisture relative to both middle Holocene and modern conditions. In the Sheep Range, the Canyon Two-1(1) midden sample (1,990±70 B.P.), at an elevation of 1,740 m, contains abundant juniper and common pinyon pine (fig. 14). An older sample from this midden, CT-1(2) at 3,310±100 B.P., contains only occasional juniper and no pinyon pine. This late Holocene record of woodland vegetation comes from a site that is surrounded by blackbrush desertscrub today. The current lower limit of woodland in this part of the range (fig. 12) is at an elevation of about 2,010 m, more than 200 m above the Canyon Two site (Spaulding, 1977). Other middens from the Sheep Range that contain remains of woodland conifers 100 to 200 m below their current lower limits include the Basin Wash sample (3,520±100 B.P.) and the Ey-2(1) sample at 2,920±90 B.P. (fig. 11) (Spaulding, 1981, p. 141, p. 123-125).

Late Holocene vegetation change is evident in packrat middens from the Eureka Valley and the Specter Range. Assemblages from the Eureka Valley record final extirpation of such extralocals as indigo bush (*Psorothamnus fremontii*) cacti (*Opuntia basilaris* and *Opuntia echinocarpa*), and desert spruce (*Peucephyllum schottii*), between about 1,600 B.P. and the present (fig. 24). A decline in the proportion and amount of summer precipitation may have caused local extinction of indigo bush and cacti. However, it is likely that lower winter temperatures eliminated desert spruce from this northern-most documented occurrence. The closest locality where *Peucephyllum* occurs today is on south-facing slopes of the Last Chance Range of California, 12 km southeast of the Eureka Valley sites.

Two assemblages from the Specter Range-1 site document desertscrub vegetation analogous to today's, although there appears to have been a shift in plant-community composition. Fourwing saltbush (*Atriplex canescens*) is the most abundant species in the sample dated at 300±100 B.P. [sample Spc-1(1)], while creosote bush and matchweed (*Gutierrezia microcephala*) are more important in the younger Spc-1(2) assemblage (100^{+200}_{-100} B.P.) (table 6). This apparent shift to a xerophytic plant community in the last 300 radiocarbon years may be because of climatic change. An equally likely cause may be the effect of cattle grazing in the late 19th and early 20th century. A decline in the more palatable saltbush and an increase in unpalatable and disturbance-indicator shrubs (*Larrea divaricata*, *Gutierrezia microcephala*, *Hymenoclea salsola*) support the latter hypothesis. Similar observations are possible based on the data from subrecent packrat middens from the Eureka Valley (Spaulding, 1980).

ASSESSING PALEOENVIRONMENTAL RECONSTRUCTIONS

Packrat-midden analysis affords a high-resolution view of the environmental history of the Nevada Test Site and vicinity. However, potential errors and unknown variables that exist should be considered. Errors could be introduced in estimating modern climates at the fossil sites, in reconstructing past vegetation, or in extrapolating climatic parameters from reconstructions. Retrodictive studies, such as this one, describe phenomena that no longer exist; conclusions derived from such analyses cannot be tested through observation. However, they can be tested by attempts to replicate the fossil record and by application of proposed paleoclimatic parameters to models of physical systems, such as pluvial lakes and cryogenic deposits.

Accuracy of Representation and General Analogs

Plant-macrofossil assemblages from ancient packrat middens possess distinctive characteristics that permit identification of specific vegetation types. Analyses of modern middens in this study, and those performed by Cole (1981, p. 36-41; 1982), indicate that sufficient fidelity exists in the midden-vegetation relationship to permit accurate reconstruction to at least the community-type level (table 1). The possibility that first-order errors have been made in this study (such as reconstruction of juniper woodland when ponderosa-pine forest was actually present) is remote. Errors may exist in second-order reconstructions of specific plant associations (table 1), but this also is unlikely. Analyses of modern packrat middens show that plant species that are abundant or common in nearby vegetation are well-represented in the assemblages. Therefore, it is unlikely that a macrofossil assemblage would be interpreted as representing, say, a juniper-shrub woodland, when a pinyon-juniper woodland was actually present. Studies of modern middens thus far have failed to demonstrate consistent biases in foraging behavior of packrats that would invalidate the conclusions presented here. These paleoecological reconstructions usually are based on multiple macrofossil assemblages controlled by multiple radiocarbon dates. Non-representative assemblages may be sampled on occasion, but these would have little effect on paleoecological reconstructions based on many samples.

Diverse bioclimatic regions of the western United States provide a range of general analogs to the fossil records that are used to infer the nature of late Quaternary climates. Use of such analogs provides an effective paleoenvironmental tool, even though exact analogs between vegetation and environments of the late Pleistocene and those of today probably do not exist (Hare, 1976; Birks, 1981). Thus, the climate that existed at the time when xerophytic juniper woodland was widespread is assumed to have been more similar to that of current dry woodland than to that of less similar vegetation types in existence now. There are no logical alternatives to the assertion that, because the late Wisconsin vegetation of the Nevada Test Site region resembled current vegetation of northern Nevada, the past climate probably was more similar to the present climate of that area than any other area.

The fossil record provides evidence for various paleoecological phenomena which, in turn, are used to reconstruct different aspects of the past climate. Among the most important used in this study are values of the relative vertical displacement of individual species and the inferred absence of particular taxa from the region during the late Wisconsin.

Elevational Displacement

Estimates of minimum elevational displacement of limber pine and Utah juniper (table 8) are based on a large data set. Contributing environmental variables, such as aspect, exposure, and substrate, were considered in the calculation of displacement estimates (Spaulding, 1981, p. 166-171). Wells (1977, p. 238) has cautioned that a vertical uncertainty of 100 m may exist in such estimates, because of the possibility of downslope transport of plant fragments from higher elevations. This is balanced, to some extent, by the probability that the lowest fossil record of a particular species does not reflect the lowest elevation that it attained. Neither consideration should seriously affect the validity of minimum estimates. For example, the three lowest fossil records of limber pine on calcareous substrate in the region are within 50-m elevation of each other and are from different sites (Spaulding, 1981, table 35). At one of these sites, Basin Canyon-1 at an elevation of 1,635 m in the Sheep Range (Spaulding, 1981, p. 136-140), limber pine is well-represented in the macrofossil assemblages. It is improbable that these fossils represent downslope transport, because: (1) They are present in quantity; (2) the locality does not possess extreme topographic relief (Spaulding, 1981, fig. 20); and (3) two other middens from a different locality provide similar elevational records.

Occurrence of limber pine and Utah juniper far below their lowest modern populations is attributed to cooler summers during the late Wisconsin. These two taxa were chosen as indicator species of summer temperatures because they are the most xerophytic arboreal taxa in present subalpine (limber pine) and woodland (Utah juniper) vegetation. The assumption is made that their downward displacement primarily was due to increased effective moisture caused by lowered temperatures, not by increased precipitation. The alternative that their expansion was due to a relative increase in rainfall is less likely. An increase in precipitation exceeding 50 percent of current amounts would have resulted in the expansion of mesophytic species (such as ponderosa pine or spruce) absent in the regional fossil record. Moreover, summer temperatures, rather than winter or average annual temperatures, are considered the critical variable controlling the lower limit of these trees because moisture deficits caused by higher temperatures occur during the summer.

There are no independent means available to test validity of lapse rates (table 8) used to convert estimates of minimum elevational displacement to estimates of changes in summer temperature (ΔT_s). However, it is perhaps less likely that actual Wisconsin-maximum lapse rates deviated significantly from values used here (table 8). Indeed, values of ΔT_s derived from the fossil records of Utah juniper and limber pine are close to those proposed by other workers using quite different methods (table 7).

Negative Evidence

Absence of a species from a particular region is an important consideration in the study of present biogeographic and bioclimatic phenomena. Absence of shrubs intolerant of extremely low nocturnal temperatures, such as creosote bush, from the northern reaches of the Nevada Test Site is an indication of the severity of that region's winters (Beatley, 1974, 1975). Unfortunately, it is impossible to demonstrate conclusively with the fossil record that a particular species was not present somewhere in the region. Despite comprehensive collections, the past vegetation of some habitats, such as alluvial fans, remains unknown. Some species may have been restricted to isolated sites with favorable microclimates during the Wisconsin. However, this would not invalidate the observation that the climate of that period did not favor those species. In the face of a large data base, it would be less reasonable to claim that these inferences are impermissible simply because they are based on negative evidence. However, negative inferences should be drawn from large data sets only and supported by other lines of evidence, and there is always the need for further replication.

Absence of creosote bush from the Wisconsin fossil record is attributed to winter temperatures that ranged below the limit of tolerance of that species. To this assumption can be added one qualification based on the possibility of competitive exclusion. Today certain habitats exist that are warm enough in the winter to support creosote bush; however, creosote bush is rare or absent. These sites are characterized by higher rainfall, and, in the vicinity of the Nevada Test Site, such plant communities usually are dominated by blackbrush and, occasionally, species of *Lycium* (Beatley, 1974, p. 255). Although competition between plants is difficult to demonstrate (Grime, 1979), it is likely that creosote bush is absent from these communities because species such as blackbrush are more robust competitors in somewhat wetter habitats. Absence of creosote bush from the fossil record also may be due to such competitive exclusion, but it is considered unlikely. Many plant taxa that were common at lower elevations during the Wisconsin are typical of habitats that are too cold today for creosote bush. Plant species such as blackbrush are rare in the fossil record in the vicinity of the Nevada Test Site prior to about 12,000 years ago.

Radiocarbon Dating

Accurate radiocarbon dating of packrat middens is crucial to these paleoclimatic reconstructions. Mindful of past debates over methods in packrat-midden dating (Van Devender, 1977a; Wells, 1977), considerable care was taken in both the collection and description of ancient middens, and in the selection of samples for detailed analysis. As mentioned previously, less than 50 percent of the indurated middens located in the field were collected. Further examination and dissection of midden samples in the laboratory led to the rejection of others, on the basis of poor stratigraphic integrity and possible mixing of different-age plant debris. It is believed that many potential dating errors can be avoided by such rigorous sample selection. Reliability of these results is enhanced further by the use of time series from single sites. In a site-specific context, anomalous samples can be recognized more easily and subjected to further radiocarbon analyses. Therefore, there is little reason to suspect serious errors in the inferred vegetation associations or in the chronologies of vegetation and climate change presented here.

FUTURE CLIMATIC CHANGE

Various mechanisms operate on different scales of time (wavelengths) to affect climate. They range from diurnal solar forcing, with a frequency measured in hours, to epeiorogenic-orogenic events with a quasi-periodicity of, perhaps, between 10 to 100 million years (Mitchell, 1976, p. 482-485). Based on current knowledge of climate dynamics and the geological record of past changes, major global climatic fluctuations likely will occur within the next 10,000 years. This is within the hazardous lifespan of radioactive wastes contemplated for storage at the Nevada Test Site. Although any prediction of the impact of future climatic change on the environment of the Nevada Test Site is untestable (except indirectly by climate modeling) and speculative, it is nevertheless a critical aspect of overall assessment of site suitability.

Recent studies point to two separate phenomena as likely forcing mechanisms that may cause significant climatic change in the next 10,000 years. These are increases in global atmospheric carbon dioxide and changes in the elements of the Earth's orbit. Each is operating on a different time frequency. The former is anthropogenic and is occurring on periods of 100 years and less. Surface-troposphere warming caused by increasing atmospheric carbon dioxide concentrations is rapid enough that the effects may be visible before the end of the century (Kellogg and Schware, 1981; Schlesinger, 1983). However, the combined effect of three orbital parameters that appear to drive the glacial-interglacial cycles [axial tilt, eccentricity, and deviation of the earth-sun distance (precession)] has demonstrable cycles of 10,000 to 100,000 years. Because climate changes caused by astronomic modulation of solar insolation are of lower frequency, their immediate effects are not as apparent.

Atmospheric Carbon Dioxide

Likely consequences of increased atmospheric carbon dioxide have been identified using both general circulation and radiative-convective models of global climate (Ramanathan and Coakley, 1978; Manabe and Stouffer, 1979). Most analyses are based on a projected doubling or quadrupling of carbon dioxide content of the atmosphere within the next 400 years. The result will be an increase in heating the surface-troposphere system by reflection of long-wave radiation from the Earth. The models of Ramanathan and others (1979, p. 4956) predict an increase in northern-hemispheric mean surface temperature of 3.2°C, assuming a doubling of atmospheric carbon dioxide. Manabe and Wetherald (1975, p. 9) note that a consequence of doubled atmospheric carbon dioxide concentration is the increase in heat energy available for evaporation. Hence, intensity of the "hydrologic cycle" (the entire ocean-land, evaporation-precipitation system in this case) would be enhanced, in their model, by about 7 percent. A projected increase in rainfall also is implied by intensification of subtropical high-pressure systems by tropospheric warming (Manabe and Wetherald, 1975, p. 13). Schlesinger (1983) has recently reviewed model simulations of CO_2-induced climate change.

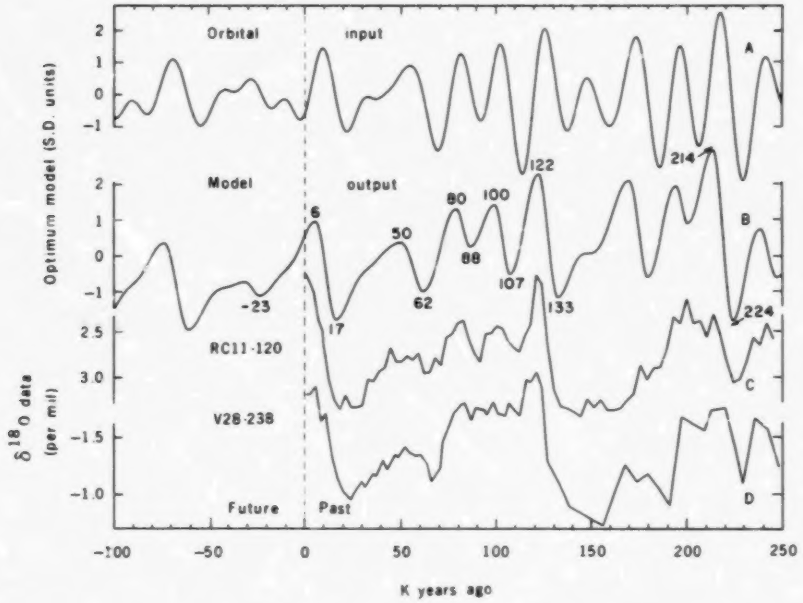
In general, the projected relation of increased atmospheric temperatures to increased precipitation is analogous to paleoclimatic reconstructions that indicate an increased flow of tropical maritime air to land during latest Wisconsin and middle Holocene. Increased temperatures during the early postglacial may have led to an enhanced summer monsoon in subtropical arid regions (Kutzbach, 1981, p. 60; Bryson and Swain, 1981, table 2). Another feature shared by both models, those used to predict the effect of carbon dioxide heating and those used to reconstruct the impact of increased insolation, is considerable seasonal and latitudinal variability in results (Ramanathan and others, 1979, p. 4956; Broecker and van Donk, 1970, p. 188; Kutzbach, 1981, p. 61).

The most important possible consequence of the increase in radiative heating of the surface-troposphere system is melting of the Antarctic ice cap (Etkins and Epstein, 1982; Kukla and Gavin, 1981). Obviously, the resultant rise in sea level will have no direct effect on the environment of the Nevada Test Site. However, the anticipated rise in temperatures may well have a significant impact on the general climate of the Southwest and the Nevada Test Site in particular. Summer temperatures are expected to be higher than at present by a minimum of about 3°C. Monsoonal circulation also will be enhanced. An increase in summer and fall precipitation by as much as 50 to 100 percent over current amounts is not unrealistic (Bryson and Swain, 1981, table 2). This relative increase in precipitation is dependent on: (1) Intensity of the warming; (2) accuracy of current model atmosphere projections; and (3) proximity of any given site to the source of maritime air. Because the Nevada Test Site is beyond the influence of monsoonal rains today, it is reasonable to anticipate less increase in annual rainfall here (perhaps no more than 50 percent) than in areas farther south and east.

The Next Ice Age

The relationship between variations in the Earth's orbital configuration and the record of ice-sheet contraction and expansion is well-documented (Imbrie and Imbrie, 1980). The astronomical theory of climate states that modulation of solar radiation by changes in precession, obliquity, and eccentricity is the principal cause of Pleistocene ice ages. In particular, the Milankovitch model (Imbrie and Imbrie, 1980) relates orbitally controlled decreases in northern latitude summer insolation to the descent of snowline and development of perennial snowfields (Adam, 1975; Johnson and McClure, 1976). Several feedback mechanisms then would enhance their growth to continental ice sheets (Ruddiman and McIntyre, 1981, p. 617-618). In a like manner, deglaciation such as that which occurred at the end of the Wisconsin are associated with peaks in summer insolation in the northern hemisphere (Broecker and van Donk, 1970, fig. 10; Ruddiman and McIntyre, 1981).

Given the inherent predictability of orbital parameters affecting incident solar radiation, and an adequate statistical model relating these variations to continental glaciation, future major global climate change can be predicted. Broecker and van Donk (1970, p. 194) were among the first to observe that, based on their analyses, " *** the next 50,000 years should see unusually rapid expansion of continental ice sheets." This agrees with the subsequent work of Berger (1978, fig. 4e) that presents variations in astronomical parameters and insolation curves for the next 250,000 years. A minimum in northern-hemispheric summer insolation will occur within the next 10,000 years. That this may result in initiation of a new glacial age is seen in the model projections of Imbrie and Imbrie (1980, figs. 7 and 8). Their nonlinear model was constructed to simulate global climatic response to orbital variations, as observed in the deep-sea core record of $^{16}O/^{18}O$ variations. After adjustment and tuning, good agreement was reached between the model's response to orbital input and the actual oxygen-isotope record of continental glaciation over the last 250,000 years (fig. 25). The model's response to future orbital input is seen as a continuation of the cooling trend that has been underway for about the last 6,000 years, culminating in a glacial maximum in about 60,000 A.P. (years after present). Another, less-pronounced stade is evident in the model output at about 23,000 A.P. (fig. 25). The gradual excursion of global climate to maximum stadial conditions, followed by relatively abrupt deglaciation after 60,000 A.P., is consistent with the "sawtooth" character of the primary glacial-interglacial cycle (Broecker and van Donk, 1970; Ruddiman and McIntyre, 1981, p. 625).



From Imbrie and Imbrie, 1980. Copyright 1980 by the American Association for the Advancement of Science.

Figure 25.--Inferred past changes in global ice volume and modeled future trends (from Imbrie and Imbrie, 1980, p. 948; copyright 1980 by the American Association for the Advancement of Science); orbitally induced irradiation variations for July at lat 65° N. are presented in A; resultant output of Imbrie and Imbrie's (1980, fig. 7) optimum climatic response model is shown in B; fluctuations in world ice-sheet volume are recorded in oxygen-isotope variations in two equatorial deep-sea cores Rc11-120 and V28-238 (C and D).

In this context, it is useful to reaffirm the statement that the Wisconsin maximum at about 18,000 B.P. represents a maximum departure from current interglacial conditions. The magnitude of that stadial episode generally is representative of what may be expected during the next glacial maximum, based on oxygen-isotope record estimates of global ice volume. The last four glacial maxima, during isotope stages 2, 6, 8, and 10, all appear to have been of comparable magnitude, as is the projected maximum at about 60,000 A.P. The implication that there is an approximately equivalent limit to each glacial buildup, attained immediately preceding each deglaciation, is supported by studies of the mechanisms of continental glaciation (Ruddiman and McIntyre, 1981; Broecker and van Donk, 1970).

The combined potential impact of changing atmospheric carbon dioxide concentrations and orbitally induced solar-insolation variations can be summarized as follows: A brief but pronounced "super-interglacial" may well occur within the next 500 years, followed by a continued trend to the next glacial age, reaching a maximum in about 60,000 years. The relative duration of the former event may be quite brief, perhaps no more than a short-lived perturbation in the progression of glacial ages. While more modeling is needed, it is doubtful that the carbon dioxide induced warming of the global climate will permanently affect the orbitally forced cycle of glacial ages.

SUMMARY AND CONCLUSIONS

Packrat middens provide an elaborate history of the late Quaternary environments of the Nevada Test Site. Radiocarbon-dated plant-macrofossil assemblages allow reconstruction of both the past vegetation and chronology of its change over the last 45,000 radiocarbon years. These, in turn, are the basis of models of local and regional paleoclimate. Nearly 100 individually dated macrofossil assemblages from the northern Mojave Desert, spanning 1,600 m of vertical relief, allow detailed characterization of the climatic stability of this region in general and the Nevada Test Site in particular.

A limited number of studies in western North America present paleoenvironmental reconstructions defined by specific climatic parameters (table 8). Because of the uncertainties inherent in such investigations (Hare, 1976; Birks, 1981; see also the fifth chapter of this report), many analyses resort to generalized conclusions. However, terms such as "equable," "pluvial," and "mild" are of limited use unless specified by a range of absolute values. Only explicit estimates can be used to model response of hydrologic systems to climatic change, and to test alternative models of past climates. Quantitative paleoclimatic estimates in this study (table 10) do incorporate a number of uncertainties that have been discussed previously. Therefore, the climatic reconstructions are expressed as either a range of values or as a limiting (maximum or minimum) parameter.

Table 10.--*Summary of estimates of late Quaternary climate for the Nevada Test Site and vicinity*

[ΔT_w, estimated changes in °C (degrees Celsius) of average winter temperature; ΔT_s, estimated changes in °C of average summer temperature; ΔT_a, estimated changes in °C of average annual temperature; % (percent) P_s, estimated percent changes in average summer precipitation relative to current amounts; $\%P_w$, estimated percent changes in average winter precipitation relative to current amounts; $\%P_a$, estimated percent changes in average annual precipitation relative to current amounts; B.P., years before present]

Time (B.P.)	ΔT_w	ΔT_s	ΔT_a	$\%P_s$	$\%P_w$	$\%P_a$
45,000	-2 to -3	---	-1 to -3	[1]-60	+20	0
38,700	---	---	-1 to -2	-40	+25 to +50	+10 to +20
37,800	---	---	-5	---	---	+20
30,000	---	---	-3 to -6	---	---	+10 to +25
18,000	[1]-6	-7 to -8	-6 to -7	-40 to -50	+60 to +70	+30 to +40
10,000	-1 to -2	+1 to +2	0	[2]+50	0	+10 to +20

[1] Minimum estimate.

[2] Maximum estimate.

During the Wisconsin, plant communities differed in both distribution and composition from plant communities of today. Environmental gradients governing altitudinal segregation of plant species into vegetation zones were altered, and a different scheme of zonation was the result (figs. 14, 22). In a region that now supports desert vegetation, Utah juniper woodland extended from near local base level up to a transition with limber pine woodland. Great Basin Desert plants, such as sagebrush, shadscale, and rabbitbush, were common in these woodlands. Although there is no evidence for vegetation without trees prior to about 15,000 years ago, steppe-shrub communities may have existed on alluvial fans unsampled by the midden method (Thompson and Mead, 1982) and on isolated, xeric habitats. There also is no evidence for glacial-age temperate-montane forest at higher elevations. Based on the macrofossil data, only two Wisconsin vegetation zones can be identified: Xerophytic pygmy-conifer woodland at low elevations (less than 1,800 m) and subalpine-conifer woodland above that. This contrasts with the present sequence of vegetation zonation from desertscrub to, first, pygmy conifer woodland; then, montane forest; and, finally, subalpine woodland (fig. 14). Not only was vegetation zonation during the Wisconsin simpler than today's, but plant associations also appear to have been less diverse. Many Mojave Desert species are rare or missing from the macrofossil record, as are many woodland and forest plants presently found in mild, moist environments.

The local chronology of climatic change is consistent with the global record of transitions from middle to late Wisconsin and from late Wisconsin to Holocene. Records of middle Wisconsin interstadial (about 45,000 to 23,000 years ago) environments document xerophytic juniper shrub associations at most sites. This was a time of reduced summer rainfall and accentuated winter precipitation. Average annual precipitation during the most mesic phase was perhaps as much as 20 percent above current amounts. The available record indicates that the warmest part of the middle Wisconsin was between about 45,000 and 39,000 years ago, with average annual temperatures perhaps only 1° to 3°C below current values (table 10). Temperatures declined in the last 10,000 to 15,000 years of the middle Wisconsin interstadial, although there appear to have been marked reversals characterized by higher temperatures.

The descent of subalpine woodland to at least an elevation of 1,800 m in the Eleana and Sheep Ranges marks the beginning of the late Wisconsin stade (about 23,000 to 10,000 years ago) in this region. In the Specter Range, a vegetation turnover from juniper-shrub to pinyon-juniper woodland by about 19,000 B.P. may be evidence of the Wisconsin maximum. The northern Mojave fossil record provides no evidence for either equable temperatures (cool summers and warm winters) or a pluvial precipitation regime (annual rainfall exceeding 50 percent of current amounts). Late Wisconsin vegetation of the Nevada Test Site and vicinity was dominated by subalpine, dry woodland, and steppe species; it lacked frost-sensitive taxa and was of apparent lower diversity. A cold, continental climate with winter temperatures at least 6°C below those of today is indicated. Summer temperatures were depressed at least an equivalent amount, and average annual temperatures were perhaps 6° to 7°C lower than at present (table 10). There was a distinct lack of summer rain and a relative increase in winter precipitation by as much as 70 percent above current values. However, the estimated increase in average annual precipitation was, at the most, about 40 percent above present amounts (table 10).

This reconstruction of late Wisconsin climate in the northern Mojave Desert differs to some extent with reconstructions proposed for the monsoonal Sonoran and Chihuahuan Deserts to the south and east. Macrofossil evidence from that region has been interpreted as indicating both a pluvial precipitation regime and equable temperatures (Van Devender, 1973, table 3; Van Devender and Spaulding, 1979, p. 708; Wells, 1979, p. 311). Contrasts between inferred paleoclimates in the vicinity of the Nevada Test Site and those to the southeast may be accounted for by regional climatic variations. The relative increase in late Wisconsin precipitation in the Sonoran and Chihuahuan Deserts apparently was greater than in the Mojave Desert. Two factors can account for this. First, an enhanced zonal (west to east) flow of upper-level air, coupled with southerly displacement of winter storm tracks, may have occurred as a consequence of a steepened arctic-equator temperature gradient during the late Wisconsin. The resultant increase in the frequency of Pacific-type winter storms is postulated to have been most pronounced south of lat 36° N. To the north, the relative increase in winter precipitation probably was less due to the barrier to easterly maritime air flow posed by the Sierra Nevada (fig. 1) (Van Devender and Spaulding, 1979, p. 708). A second factor is attenuation of the present southeast-northwest cline of summer precipitation during the late Wisconsin. The northern Mojave, which today receives roughly 25 percent of its annual increment of precipitation during the summer, may have received practically no warm-season rainfall during the late Wisconsin. Farther to the south and east, there is evidence for some summer rainfall (Van Devender, 1973, p. 88), although it probably was less than today's amounts (Van Devender and Wiseman, 1977, p. 21).

The relative decline in full-glacial (about 18,000 B.P.) temperatures proposed for the Nevada Test Site area, in the northern Mojave Desert (table 10), is roughly twice that estimated for sites in the current Sonoran Desert (Van Devender, 1973, table 3). This may be due, in part, to the pluvial environment and more southerly position of the latter region. Increased relative humidity and cloud cover would lead to relatively warm nocturnal temperatures. However, the evidence for very mild late-glacial winters in the monsoonal Southwest is equivocal. For example, the presence of chuckwalla (*Sauromalus obesus*) and desert tortoise (*Gopherus agassizi*) in the late Wisconsin woodlands of the Sonoran and Chihuahuan Deserts has been a basis for inferring a negligible decline in winter temperature (Van Devender and others, 1977, p. 61; Van Devender and Mead, 1978, p. 474). However, these animal species today occur as far north as Beatty, Nevada, where the mean January temperature is about 4.5°C (table 4). Their presence in late Wisconsin woodlands in the vicinity of Tucson, Arizona (mean January temperature of about 9.8°C) would be consistent with winter temperature decline of at least 5°C. Winter temperatures at least 5°C lower than at present also would explain the absence from the fossil record of many frost-sensitive subtropical plants characterizing the present Sonoran Desert (Van.Devender, 1976, p. 65; Spaulding and others, 1983).

Vegetation change marking the end of the late Wisconsin was underway by at least 14,000 years ago in the northern Mojave Desert. At higher altitudes, the Wisconsin to Holocene transition (about 12,000 to 8,000 B.P.) is seen as the demise of subalpine conifer associations and inception of the present pinyon-juniper woodland and ponderosa pine forest. Below an elevation of about 1,800 m, the transition was characterized by extirpation of woodland plants and development of desertscrub vegetation. This major environmental change was both space- and time-transgressive (fig. 14). At sensitive sites, postglacial vegetation conditions were attained before about 12,000 years ago and, at more "complacent" sites, after 9,500 B.P. Widespread desert vegetation developed at least 2,000 years earlier in the Mojave than in most areas of the Sonoran and Chihuahuan Deserts.

Climatic change of the Pleistocene to Holocene transition involved apparent concurrent increases in annual temperatures and summer rain, as well as a decline in winter precipitation. From about 11,000 to 10,000 years ago summer precipitation may have been as much as 50 percent higher than at present, although annual amounts in the northern Mojave probably were within 20 percent of current values (table 10). Late persistence of woodlands at low elevations in the Sonoran and Chihuahuan Deserts (Van Devender, 1977b) probably was due to this period of enhanced monsoonal precipitation. Annual range of temperatures at this time probably was somewhat greater than at present, with cooler winters and warmer summers. Winter temperatures increased into the Holocene; the middle Holocene (between 8,000 and 3,000 B.P.) may have been characterized by average annual temperatures 1° to 2°C above present values. Summer precipitation probably exceeded present amounts until between 3,000 and 4,000 years ago.

Gradually declining temperatures have typified the last 4,000 to 6,000 years. It is likely that, at present, this trend is being reversed by heating caused by increasing atmospheric carbon dioxide concentrations. Temperatures in excess of 3°C above present values and increased rainfall may occur within the next 500 years. However, this anticipated "super-interglacial" interval is not expected to permanently reverse the orbitally driven trend toward the next ice age. If current theoretical models are adequate, then a new glacial age is to be expected within the next 10,000 years.

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Supplemental Data:

Modern packrat middens. [Data from modern packrat middens analyzed in this study, tables 11-15.]

Ancient packrat middens. [Data from ancient packrat middens analyzed in this study, tables 16-25.]

Table 11.--*Plants in a recent midden from the Owl Canyon-3 site and plants growing in three habitats within 30 meters*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity; SW, southwestern; NW, northwestern]

Species	Modern vegetation (relative abundance)			Recent midden count
	SW slope	NW slope	Wash	
Ambrosia dumosa	(4)	(3)	(3)	55
Amphipappus fremontii	(1)	(3)	-	3
Aristida sp.	-	-	-	50
Asteraceae undet.	-	-	-	165
Atriplex confertifolia	-	-	-	4
Boraginaceae undet.	-	-	-	9
Brickellia arguta	(1)	-	-	2
B. desertorum	(1)	-	-	10
Bromus rubens	(1)	(2)	-	1
Cheilanthes feei	(X)	-	-	-
Chorizanthe brevicornu	-	-	-	9
Cryptantha sp.	(1)	(1)	(1)	76
Echinocactus polycephalus	(2)	(1)	(1)	7
Ephedra torreyana	(1)	-	(1)	-
Ephedra sp.	-	-	-	7
Eriogonum heermannii	-	(1)	-	4
Erioneuron pulchellum	(2)	-	(1)	15
Eucnide urens	(3)	(1)	(1)	125
Festuca octoflora	(1)	-	-	-
Galium stellatum	-	(1)	-	-
Gilia rippleyi	(X)	-	(X)	-
Gutierrezia microcephala	(4)	(5)	(4)	453
Haplopappus brickellioides	(1)	(1)	-	-
Hilaria rigida	-	-	(2)	-
Larrea divaricata	(1)	(2)	-	764
Linanthus sp.	-	-	-	172
Nicotiana trigonophylla	(1)	-	-	-

Table 11.--*Plants in a recent midden from the Owl Canyon-3 site and plants growing in three habitats within 30 meters*--Continued

Species	Modern vegetation (relative abundance)			Recent midden count
	SW slope	NW slope	Wash	
Opuntia basilaris	(1)	-	-	-
Peucephyllum schottii	(3)	(3)	-	56
Physalis crassifolia	-	-	-	1
Plantago sp.	-	-	-	4
Pleurocornis pluriseta	(3)	(1)	-	-
Poaceae undet.	-	-	-	15
Prunus fasciculata	(1)	-	-	-
Salvia dorrii	-	(1)	(3)	21
Sitanion hystrix	(1)	-	-	-
Sphaeralcea ambigua	(1)	(1)	(1)	35
Stipa arida	(1)	-	(2)	6
NISP	-	-	-	2,069
N	24	15	12	26
N_{ts}	16	12	7	14

IS (SW slope vegetation to recent midden): 73

IS (NW slope vegetation to recent midden): 77

IS (wash vegetation to recent midden): 67

Number of plant taxa in midden debris, not observed in vegetation: 6

Number of plant taxa in local vegetation, not observed in the midden: 7

Table 12.—*Plants in a recent midden from the Last Chance Range site and those growing within 30 meters*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

Species	Modern vegetation (relative abundance)	Recent midden count
Ambrosia dumosa	(4)	127
Asteraceae undet.	-	71
Atriplex confertifolia	(3)	189
Boraginaceae undet.	-	11
Brickellia desertorum	(1)	35
Bromus rubens	(3)	12
Buddleja utahensis	(3)	45
Cheilanthes feei	(X)	-
Chorizanthe brevicornu	(X)	2
C. rigida	(X)	1
Cryptantha sp.	-	14
Echinocactus polycephalus	(1)	5
Ephedra funerea	(1)	-
E. torreyana	(1)	-
Ephedra sp.	-	52
Eriogonum fasciculatum	(1)	-
E. heermannii	(1)	-
E. inflatum	(X)	-
Eriogonum sp.	(X)	11
Erioneuron pulchellum	(1)	9
Eucnide urens	(3)	74
Galium stellatum	(1)	-
Gilia sp.	(X)	6
Gutierrezia microcephala	(2)	1
Haplopappus brickellioides	-	2
Larrea divaricata	(4)	728
Lepidium fremontii	-	11
Lycium andersonii	(1)	-
Mirabilis sp.	-	2
Mortonia utahensis	(1)	65
Muhlenbergia porteri	(1)	-

Table 12.--*Plants in a recent midden from the Last Chance Range site and those growing within 30 meters*--Continued

Species	Modern vegetation (relative abundance)	Recent midden count
Nicotiana trigonophylla	(2)	5
Opuntia basilaris	(1)	9
Phacelia sp.	(X)	-
Plantago sp.	-	12
Pleurocoronis pluriseta	(1)	-
Poaceae undet.	-	15
Prunus fasciculata	-	4
Salvia dorrii	(1)	10
S. mohavensis	(1)	2
Sphaeralcea sp.	-	24
Stipa arida	(2)	12
NISP	-	1,566
N	31	28
N_{ts}	19	19

IS (vegetation at the site to plant debris in midden): 84

Number of plant taxa in midden debris, not observed in vegetation: 7

Number of plant taxa observed in local vegetation, but not observed in the midden: 5

Table 13.--*Plants in a recent midden from the Specter Range-2 site and those growing within 30 meters*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

Species	Modern vegetation (relative abundance) Crest	Modern vegetation (relative abundance) Slopes	Recent midden count
Ambrosia dumosa	(1)	-	-
Amphipappus fremontii	(3)	-	-
Artemisia sec. Tridentatae	-	-	2
Atriplex confertifolia	(3)	(2)	533
Boraginaceae undet.	-	-	6
Brickellia watsonii	-	(2)	-
Brickellia sp.	-	-	1
Bromus rubens	(2)	(2)	7
Buddleja utahensis	-	(2)	28
Cryptantha confertiflora	-	(X)	-
Echinocactus polycephalus	(1)	-	-
Ephedra torreyana	(2)	(3)	262
Eriogonum deflexum	-	(X)	-
E. heermannii	(1)	(3)	6
E. inflatum	(X)	-	-
Fendlerella utahensis	-	-	3
Galium stellatum	(1)	(1)	-
Gilia sp.	-	-	2
Gutierrezia microcephala	(3)	(3)	20
Haplopappus brickellioides	-	(1)	3
Krameria parvifolia	(1)	(1)	-
Larrea tridentata	1/	-	1
Leptodactylon pungens	(1)	-	81
Lycium andersonii	-	(1)	-
Oryzopsis hymenoides	-	-	1
Poaceae undet.	-	-	27
Prunus fasciculata	(1)	(3)	103

Table 13.—*Plants in a recent midden from the Specter Range-2 site and those growing within 30 meters*—Continued

Species	Modern vegetation (relative abundance)		Recent midden count
	Crest	Slopes	
Salvia dorrii	(2)	(1)	14
Scopulophila rixfordii	-	(3)	151
Sitanion hystrix	-	(1)	-
Sphaeralcea ambigua	(1)	-	-
Sphaeralcea sp.	-	-	9
Stipa arida	(1)	(2)	-
Stipa sp.	-	-	1
Thamnosma montana	(2)	(1)	4
NISP	-	-	1,266
N	18	19	23
N_{ts}	13	12	15

IS (crest vegetation to recent midden debris): 64

IS (slope vegetation to recent midden debris): 74

Number of plant taxa in midden debris, not observed in vegetation: 5

Number of plant taxa in local vegetation, not observed in the midden: 5

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[1] Present but more than 30 meters from the site.

Table 14.—*Plants in a recent midden from the Eleana Range-3 site and those growing within 30 meters*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

Species	Modern vegetation (relative abundance)	Recent midden count
Artemisia nova	(2)	-
A. tridentata	(3)	-
Artemisia sec. Tridentatae	-	19
Atriplex canescens	(4)	387
Boraginaceae undet.	-	10
Brickellia californica	(1)	-
Bromus rubens	(X)	-
Cowania mexicana	(1)	153
Cryptantha confertiflora	(X)	-
Cryptantha sp.	-	1
Ephedra torreyana	(1)	-
E. viridis	(2)	-
Ephedra sp.	-	16
Eriogonum caespitosum	(1)	-
E. fasciculatum	(1)	-
E. inflatum	(X)	-
E. microthecum	(1)	-
Festuca sp.	(1)	-
Forsellesia nevadensis	-	2
Haplopappus nanus	(2)	12
Heterotheca villosa	(X)	-
Juniperus osteosperma	(1)	75
Leptodactylon pungens	(1)	-
Linum lewisii	(X)	5
Opuntia erinacea	1/	1
Oryzopsis hymenoides	(X)	26
Penstemon sp.	-	1

Table 14.—*Plants in a recent midden from the Eleana Range-3 site and those growing within 30 meters*--Continued

Species	Modern vegetation (relative abundance)	Recent midden count
Phacelia sp.	(X)	3
Pinus flexilis	-	3
P. monophylla	(2)	79
Poaceae undet.	-	177
Purshia tridentata	-	1
Quercus gambelii	1/	2
Rhus trilobata	(1)	5
Salvia columbariae	(X)	-
Senecio multilobatus	(X)	-
Sphaeralcea sp.	(1)	17
Stanleya pinnata	(1)	-
Stipa sp.	(3)	-
Symphoricarpos longiflorus	(2)	-
Symphoricarpos sp.	-	4
NISP	-	999
N	29	22
N_{ts}	16	15

IS (current vegetation to recent midden debris): 77

Number of plant taxa in midden debris, not observed in vegetation: 6

Number of plant taxa in local vegetation, not observed in the midden: 9

1/ Present but not more than 30 meters from the midden.

Table 15.--*Plants in recent midden debris from the Connley Hills-1 and -2 sites, and those growing within 30 meters of each locality*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

Species	Connley Hills-1		Connley Hills-2	
	Modern vegetation (relative abundance)	Recent midden count	Modern vegetation (relative abundance)	Recent midden count
Amsinckia sp.	(X)	2	-	-
Artemisia tridentata	(4)	25	(3)	138
Boraginaceae undet.	-	8	-	-
Brassicaceae undet.	(X)	-	-	-
Bromus tectorum	(2)	35	(3)	18
Chenopodium cf. *botrys*	-	-	-	50
Chrysothamnus nauseosus	(5)	37	(5)	230
C. viscidiflorus	(1)	2	(1)	-
Chrysothamnus sp.	-	148	-	40
Descurainia sp.	(X)	11	(X)	97
Juniperus occidentalis	(1)	432	(3)	1,059
Oryzopsis hymenoides	-	8	-	7
Poaceae undet.	(3)	904	(2)	156
Purshia tridentata	-	-	-	15
Ribes cereum	(1)	1	(1)	8
NISP	-	1,613	-	1,818
N	10	12	8	11
N_{ts}	5	5	5	6

IS (current vegetation to recent midden at Connley Hills 1): 100

IS (current vegetation to recent midden at Connley Hills 2): 91

Number of plant taxa in Connley Hills 1 midden debris, not observed in vegetation: 0

Number of plant taxa in vegetation at Connley Hills 1, not observed in the midden: 0

Number of plant taxa in Connley Hills 2 midden debris, not observed in vegetation: 2

Number of plant taxa in vegetation at Connley Hills 2, not observed in the midden: 0

Table 16.--*Plants from the Owl Canyon (OC) locality*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Owl Canyon-2			Owl Canyon-3			
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		OC-2(1)	OC-2(3)		OC-3(mod)	OC-3(1)	OC-3(2)
Approximate radiocarbon age	-	10,260	10,070	-	-	32,900	>28,700
Species							
Agave utahensis	-	706	437	-	-	324	185
Agropyron sp.	-	1	3	-	-	-	-
Ambrosia dumosa	(3)	-	-	(3)	55	-	-
Amphipappus fremontii	(1)	-	-	(2)	3	-	-
Amsinckia sp.	-	1	1	-	-	-	-
Anemone tuberosa	-	5	5	-	-	-	-
Aristida sp.	-	-	-	-	50	-	-
Artemisia sec. Tridentatae	-	-	-	-	-	2	-
Asteraceae undet.	-	5	13	-	165	-	5
cf. *Astragalus* sp. (2 spp.)	-	12	15	-	-	-	-
Atriplex confertifolia	-	2	-	-	4	41	4
Boraginaceae undet.	-	1	7	-	9	-	1
Brickellia arguta	(1)	-	-	(1)	2	-	-
B. desertorum	-	-	-	(1)	10	-	-
Brickellia sp.	-	22	51	-	-	-	-
Bromus rubens	(X)	-	-	(X)	1	-	-
Buddleja utahensis	-	83	161	-	-	4	6

Table 16.--*Plants from the Owl Canyon (OC) locality*--Continued

	Owl Canyon-2			Owl Canyon-3			
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		OC-2(1)	OC-2(3)		OC-3(mod)	OC-3(1)	OC-3(2)
Cheilanthes feei	-	-	-	(X)	-	-	-
Chorizanthe cf. *brevicornu*	(X)	-	-	-	9	-	-
Chrysothamnus nauseosus	-	-	9	-	-	468	1,345
Cirsium sp.	-	207	88	-	-	25	-
Cryptantha sp.	(X)	-	-	(X)	76	-	-
Echinocactus polycephalus	(3)	-	-	(2)	7	-	7
Encelia sp.	-	-	1	-	-	-	-
Ephedra torreyana	-	-	-	(1)	7	-	-
Ephedra sp.	-	1	-	-	-	1	-
Eriogonum heermannii	-	-	-	(1)	4	-	-
Eriogonum sp.	(X)	-	-	-	-	-	-
Erioneuron pulchellum	(2)	-	-	(1)	15	-	-
Eucnide urens	(3)	-	-	(2)	125	-	-
Fabaceae undet.	-	-	-	-	-	-	2
Fallugia paradoxa	-	2	3	-	-	2	-
Festuca octoflora	-	-	-	(X)	-	-	-
Galium stellatum	-	-	-	(1)	-	-	-
Gilia rippleyi	(X)	-	-	(X)	-	-	-
Gutierrezia microcephala	(2)	-	-	(4)	453	-	-
Juniperus osteosperma	-	-	1	-	-	[1]/	[1]/
Haplopappus brickellioides	-	-	-	(1)	-	-	-
Hilaria rigida	-	-	-	(X)	-	-	-

Table 16.--*Plants from the Owl Canyon (OC) locality*--Continued

	Owl Canyon-2			Owl Canyon-3			
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		OC-2(1)	OC-2(3)		OC-3(mod)	OC-3(1)	OC-3(2)
Larrea divaricata	(3)	-	-	(2)	764	-	-
Lepidium cf. *fremontii*	-	-	2	-	-	-	-
cf. *Leptodactylon* sp.	-	1	-	-	-	3	-
Linanthus sp.	-	-	-	-	172	-	-
Lycium sp.	-	3	-	-	-	-	-
Nicotiana trigonophylla	-	-	-	(1)	-	-	-
Opuntia basilaris	-	12	21	(1)	-	-	1
Opuntia sp.	-	-	-	-	-	130	129
Penstemon sp.	-	-	1	-	-	-	-
Peucephyllum schottii	(3)	-	-	(3)	56	-	-
Physalis crassifolia	-	-	-	-	1	-	-
Plantago sp.	-	-	-	-	4	-	-
Pleurocoronis pluriseta	(3)	-	-	(3)	-	-	-
Poaceae undet.	-	63	75	-	15	2	9
Prunus fasciculata	-	44	33	(1)	-	4	-
Psorothamnus fremontii	-	7	3	-	-	3	-
Salvia dorrii	-	17	1	(2)	21	6	7
Scopulophila rixfordii	-	91	115	-	-	279	614
Sitanion hystrix	-	-	-	(X)	-	-	-
Sphaeralcea ambigua	(1)	-	-	(1)	35	-	-
Sphaeralcea sp.	-	29	12	-	-	2	11

Table 16.--*Plants from the Owl Canyon (OC) locality*--Continued

	Owl Canyon-2			Owl Canyon-3			
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		OC-2(1)	OC-2(3)		OC-3(mod)	OC-3(1)	OC-3(2)
Stipa arida	(4)	-	-	(X)	-	-	-
Stipa sp.	-	-	3	-	6	-	-
Symphoricarpos longiflorus	-	-	-	-	-	33	34
NISP	-	1,315	1,063	-	2,069	1,329	2,360
N	17	23	24	28	26	18	16
N_{ts}	10	14	15	20	16	16	13
IS (to current vegetation)	-	8	8	-	72	27	24

[1] Very abundant (>1,000), not counted.

Table 17.--*Plants from the Point of Rocks (PR) 1 site*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional, 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count	
		PR-1(1)	PR-1(3)
Approximate radiocarbon age		9,840	11,680
Species			
Amaranthus sp.	-	-	4
Ambrosia dumosa	(2)	-	-
Ambrosia sp.	-	-	1
Amsinckia tesselata	-	1	-
Amsinckia sp.	(X)	-	-
Aristida sp.	(X)	-	-
Artemisia sec. Tridentatae	-	62	13
Asteraceae undet.	-	12	50
Atriplex canescens	-	30	10
Atriplex confertifolia	(1)	-	-
Boraginaceae undet.	-	-	1
Brickellia arguta	(2)	-	-
B. watsonii	(1)	-	-
Brickellia sp.	-	-	-
Bromus rubens	(X)	-	56
Ceratoides lanata	-	36	-
Cheilanthes feei	(X)	-	-
Chorizanthe rigida	(X)	-	-
Coleogyne ramosissima	-	8	17
Cryptantha sp.	-	-	1
Echinocactus polycephalus	(2)	-	-
Ephedra funerea	(2)	-	-
Ephedra torreyana	(1)	-	-
Ephedra sp.	-	64	-
Eriogonum inflatum	(X)	-	-
Erioneuron pulchellum	(3)	-	-
Erodium cicutarium	(X)	-	-
Eucnide urens	(2)	-	-
Forsellesia nevadensis	-	5	89
Galium stellatum	(2)	-	-

Table 17.--*Plants from the Point of Rocks (PR) 1 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count	
		PR-1(1)	PR-1(3)
Gilia sp.	-	-	1
Gutierrezia microcephala	(4)	76	152
Krameria parvifolia	(1)	-	-
Langloisia setosissima	-	-	7
Larrea divaricata	(2)	-	-
Lepidium cf. *fremontii*	-	142	-
Lepidium sp.	-	-	13
Lepidospartum latisquamum	-	25	185
Leptodactylon pungens	-	60	-
Lycium andersonii	(1)	-	-
L. pallidum	(3)	-	-
Lycium sp.	-	5	3
Menodora spinescens	-	43	14
Nicotiana trigonophylla	(1)	-	-
Opuntia basilaris	(1)	-	16
O. echinocarpa	1/	-	-
O. cf. *ramosissima*	-	-	18
Opuntia sp.	-	49	258
Penstemon sp.	(1)	-	-
Peucephyllum schottii	(1)	-	-
Phacelia sp.	(X)	-	-
Plantago sp.	(X)	1	1
Poaceae undet.	-	30	42
Porophyllum gracile	(1)	-	-
Prunus fasciculata	-	6	117
Purshia glandulosa	-	566	-
Purshia sp.	-	-	2
Salvia dorrii	-	1	-
Scopulophila rixfordii	-	-	3
Sphaeralcea ambigua	(2)	-	-
Sphaeralcea sp.	-	19	7
Symphoricarpos longiflorus	-	1	17
Thamnosma montana	(1)	2	-
Yucca brevifolia	-	12	-
NISP	-	1,256	1,098
N	31	24	28
N_{ts}	19	19	17
IS (to current vegetation)	-	37	39

1/ Species in the vicinity, but occurring more than 30 meters from the site.

Table 18.--*Plants from the Point of Rocks (PR) 2 and 3 sites*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Point of Rocks-2			Point of Rocks-3	
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count
		PR-2(2)	PR-2(3)		PR-3
Approximate radiocarbon age	-	9,560	9,260	-	14,800
Species					
Agave *utahensis*	-	186	195	-	-
Ambrosia *dumosa*	(2)	-	-	(4)	-
Amphipappus *fremontii*	(2)	3	45	(3)	-
Amsinckia sp.	(X)	2	-	(X)	5
Aristida cf. *adscensionis*	(X)	2	-	(3)	-
Artemisia cf. *bigelovii*	-	31	21	-	-
Artemisia sec. Tridentatae	-	-	-	-	2
Asteraceae undet.	-	5	30	-	14
Atriplex cf. *canescens*	-	-	1	-	-
A. *confertifolia*	(4)	-	-	(1)	415
Boraginaceae undet.	-	9	17	-	1
Brickellia *arguta*	(3)	-	-	(1)	-
Bromus *rubens*	(X)	-	-	(X)	-
Buddleja *utahensis*	-	-	-	-	11
Ceratoides *lanata*	-	-	9	-	-
Cheilanthes *feei*	(X)	-	-	(X)	-
Chorizanthe *brevicornu*	-	-	-	(X)	-
C. *rigida*	(X)	-	-	-	-
Chorizanthe sp.	-	2	-	-	-
Chrysothamnus *nauseosus*	-	-	6	-	101
Coleogyne *ramosissima*	-	66	103	-	11
Coryphantha *vivipara*	-	-	-	-	1

Table 18.--*Plants from the Point of Rocks (PR) 2 and 3 sites*--Continued

	Point of Rocks-2			Point of Rocks-3	
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count
		PR-2(2)	PR-2(3)		PR-3
Cryptantha spp.	-	4	8	-	21
Draba sp.	-	2	3	-	-
Echinocactus polycephalus	(1)	1	-	(1)	1
Encelia virginensis	-	-	3	-	-
Ephedra funerea	(1)	-	-	(2)	-
E. torreyana	(2)	96	236	(1)	-
Ephedra sp.	-	-	-	-	123
Eriogonum heermannii	-	-	-	-	5
E. inflatum	(X)	-	-	-	-
Erioneuron pulchellum	(2)	8	15	-	-
Eucnide urens	-	-	-	(2)	-
Eurotia lanata	-	-	9	(1)	-
Fallagia paradoxa	-	-	-	-	1
Festuca octoflora	-	-	-	-	-
Forsellesia nevadensis	-	-	2	(X)	4
Galium stellatum	(2)	-	-		
Gilia sp.	-	34	53		
Gutierrezia microcephala	(3)	-	-	(2)	-
Gutierrezia sp.	-	-	1	-	-
Haplopappus brickellioides	(3)	-	-	(2)	9
Haplopappus cf. *nanus*	-	-	-	-	9
Hilaria ridiga	(2)	-	-	(1)	-
Krameria parvifolia	(2)	-	-	-	-
Lappula redowskii	-	-	1	-	-
Larrea divaricata	(1)	30	2	(3)	-
Lepidium fremontii	(2)	102	8	(1)	-
Lepidium sp.	-	-	-	-	-
Leptodactylon pungens	-	1	7	-	1

Table 18.--*Plants from the Point of Rocks (PR) 2 and 3 sites*--Continued

	Point of Rocks-2			Point of Rocks-3	
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count
		PR-2(2)	PR-2(3)		PR-3
Lycium andersonii	(1)	-	-	-	-
Lycium sp.	-	-	2	-	17
Mirabilis sp.	-	2	-	-	19
Nicotiana trigonophylla	-	-	-	(2)	-
Opuntia basilaris	-	32	34	-	-
O. cf. *erinacea*	-	-	34	-	-
Oryzopsis hymenoides	(1)	2	3	-	-
Penstemon sp.	-	-	-	-	2
Petrophytum caespitosum	-	-	-	-	14
Peucephyllum schottii	(2)	-	-	(2)	-
Phacelia sp.	-	1	-	(X)	4
Pleurocoronis pluriseta	(2)	-	-	-	-
Poaceae undet.	-	57	104	-	17
Prunus fasciculata	-	-	-	-	1
Scopulophila rixfordii	-	442	220	-	-
Sphaeralcea ambigua	-	-	-	(2)	-
Sphaeralcea sp.	-	84	171	-	151
Stephanomeria pauciflora	(1)	-	-	-	-
Stipa sp.	-	-	1	-	-
Symphoricarpos longiflorus	-	1	-	-	961
Thamnosma montana	(1)	2	29	(2)	-
Tidestromia oblongifolia	-	3	18	-	-
Yucca brevifolia	-	-	-	-	13
Y. schidigera	1/	-	-	-	-
NISP	-	1,210	1,390	-	1,968
N	27	28	31	27	28
N_{ts}	17	12	18	15	18
IS (to current vegetation)	-	41	40	-	24

[1/] Species in the vicinity but occurring more than 30 meters from the site.

Table 19.--*Plants from the Last Chance Range (LCR) 1 site*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		LCR-1(mod)	LCR-1(2)	LCR-1(3)
Approximate radiocarbon age	-	-	9,280	11,760
Species				
Agave utahensis	-	-	45	76
Ambrosia acanthicarpa	-	-	-	17
A. dumosa	(4)	127	-	-
Amsinckia sp.	-	-	4	1
Anemone tuberosa	-	-	-	4
Artemisia sec. Tridentatae	-	-	-	82
Asteraceae undet.	-	71	-	6
Atriplex confertifolia	(3)	189	-	-
Boraginaceae undet.	-	11	13	1
Brickellia arguta	-	-	1	-
B. desertorum	(1)	35	-	-
Bromus rubens	(3)	12	-	-
Buddleja utahensis	(3)	45	101	9
Castilleja sp.	-	-	-	6
Cercocarpus intricatus	-	-	2	37
Cheilanthes feei	(X)	-	-	-
Chorizanthe brevicornu	(X)	2	3	-
C. rigida	(X)	1	1	-
Cirsium sp.	-	-	-	10
Cryptantha cf. *pterocarya*	-	-	1	-
Cryptantha sp.	-	14	1	5
Echinocactus polycephalus	(1)	5	1	-
cf. *Echinocereus* sp.	-	-	-	1
Encelia virginensis	-	-	14	-

Table 19.--*Plants from the Last Chance Range (LCR) 1 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		LCR-1(mod)	LCR-1(2)	LCR-1(3)
Ephedra funerea	(1)	-	-	-
E. torreyana	(1)	-	-	-
E. viridis	-	-	5	-
Ephedra sp.	-	52	-	32
Eriogonum fasciculatum	(1)	-	-	-
Eriogonum heermannii	(1)	-	-	-
E. inflatum	(X)	-	-	-
Eriogonum sp.	(X)	11	-	-
Ericneuron pulchellum	(1)	9	2	-
Eschscholtzia sp.	-	-	-	1
Eucnide urens	(3)	74	29	-
Forsellesia nevadensis	-	-	-	64
Galium stellatum	(1)	-	-	-
Gilia sp.	(X)	6	1	-
Gutierrezia microcephala	(2)	1	-	719
Haplopappus brickelliodes	-	2	7	-
Juniperus osteosperma	-	-	170	1/
Larrea divaricata	(4)	728	-	-
Lepidium fremontii	-	11	28	-
Lepidium sp.	-	-	-	29
Lesquerella sp.	-	-	1	-
Lycium andersonii	(1)	-	-	-
Lycium sp. (not *L. andersonii*)	-	-	110	14
Mirabilis sp.	-	2	-	-
Mortonia utahensis	(1)	65	854	4
Muhlenbergia porteri	(1)	-	-	-
Nicotiana trigonophylla	(2)	5	-	-
Opuntia basilaris	(1)	9	3	2
O. cf. *echinocarpa*	-	-	16	-
Opuntia sp.	-	-	-	10

Table 19.--*Plants from the Last Chance Range (LCR) 1 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		LCR-1(mod)	LCR-1(2)	LCR-1(3)
Penstemon sp.	-	-	5	-
Phacelia sp.	(X)	-	3	-
Plantago sp.	-	12	2	-
Pleurocoronis pluriseta	(1)	-	-	-
Poaceae undet.	-	15	43	13
Prunus fasciculata	-	4	-	41
Salvia dorrii	(1)	10	36	820
S. mohavensis	(1)	2	-	-
Sphaeralcea sp.	-	24	19	32
Stanleya cf. *elata*	-	-	3	-
Stipa arida	(2)	12	-	-
Symphoricarpos longiflorus	-	-	4	183
Yucca brevifolia	-	-	217	-
NISP	-	1,566	1,751	2,219
N	31	28	34	28
N_{ts}	19	19	20	18
IS (to current vegetation)	-	79	31	32

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[1] Very abundant (>1,000), not counted.

Table 20.--*Plants from the Specter Range (Spc) 2 site*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Vegetation (relative abundance)		Macrofossil assemblages sample number and count									
	Crest	Ledges and talus	Spc-2(mod)	Spc-2(2)$_1$	Spc-2(2)$_2$	Spc-2(3)	Spc-2(6)	Spc-2(8)	Spc-2(10)	Spc-2(11)$_1$	Spc-2(11)$_2$	Spc-2(12)
Approximate radiocarbon age	-	-	-	18,740	19,290	23,280	25,900	1/ 27,900	29,140	1/ 32,260	32,100	25,150
Species												
Ambrosia dumosa	(1)	-	-	-	-	-	-	-	-	-	-	-
Amphipappus fremontii	(3)	-	-	-	-	-	-	-	-	-	-	-
Artemisia sec. Tridentatae	-	-	2	1	2	48	21	4	-	9	6	5
Asteraceae undet.	-	-	2	-	-	-	-	2	8	3	-	-
Atriplex confertifolia	(3)	(2)	533	-	-	336	21	33	40	217	118	18
Boraginaceae undet.	-	-	6	1	2	-	-	-	-	1	1	-
Brassicaceae undet.	-	-	-	-	-	-	1	-	-	-	-	-
Brickellia watsonii	-	(2)	-	-	-	-	-	-	-	-	-	-
Brickellia sp.	-	-	1	-	-	-	-	-	-	-	-	-
Bromus rubens	(2)	(2)	7	-	-	-	-	-	-	-	-	-
Buddleja utahensis	-	(2)	28	-	-	-	-	-	-	-	-	-
Castilleja sp.	-	-	-	-	-	-	-	-	-	-	25	-
Ceratoides lanata	-	(1)	-	-	-	-	4	1	2	2	1	-
Cercocarpus intricatus	-	-	-	35	32	1	-	-	-	-	-	5
Chrysothamnus nauseosus	-	-	-	-	-	5	-	3	-	-	-	12
C. visidiflorus	-	-	-	1	4	3	-	-	-	-	-	-
Chrysothamnus sp.	-	-	-	-	-	-	13	-	-	-	-	-
Coleogyne ramosissima	(1)	-	1	-	-	-	-	-	-	-	-	-
Cryptantha cf. *confertiflora*	-	(1)	-	-	-	-	-	-	-	-	5	-
Echinocactus polycephalus	(1)	-	-	-	-	-	-	-	-	-	-	-
Ephedra torreyana	(2)	(3)	262	-	-	-	-	-	-	-	-	-
Ephedra sp.	-	-	-	1	2	-	-	-	-	1	-	-
Erigeron sp.	-	-	-	1	-	-	-	-	-	-	-	-

Table 20.--*Plants from the Specter Range (Spc) 2 site*--Continued

	Vegetation (relative abundance)		Macrofossil assemblages sample number and count									
	Crest	Ledges and talus	Spc-2(mod)	Spc-2(2)$_1$	Spc-2(2)$_2$	Spc-2(3)	Spc-2(6)	Spc-2(8)	Spc-2(10)	Spc-2(11)$_1$	Spc-2(11)$_2$	Spc-2(12)
Eriogonum deflexum	-	(X)	-	-	-	-	-	-	-	-	-	-
E. cf. *fasciculatum*	-	-	-	-	-	5	2	-	-	-	2	-
E. heermannii	(1)	(3)	6	-	3	2	1	-	-	-	1	5
E. inflatum	(X)	-	-	-	-	-	-	-	-	-	-	-
Fendlerella utahensis	-	-	3	138	128	28	-	6	5	100	211	7
Forsellesia cf. *nevadensis*	-	-	-	-	-	-	-	-	1	-	-	-
Galium stellatum	(1)	(1)	-	-	-	-	-	-	-	-	-	-
Gilia sp.	-	-	2	-	-	-	-	-	-	-	-	-
Gutierrezia microcephala	(3)	(3)	20	-	-	-	-	-	-	-	-	-
Haplopappus brickelliodes	-	(1)	3	-	-	-	-	-	9	-	-	-
H. cooperi - type	-	-	-	-	-	-	14	10	-	29	19	-
Hecastocleis shockleyi	-	-	-	-	-	-	-	-	-	1	4	3
Juniperus osteosperma	-	-	-	2/	2/	2/	2/	2/	2/	2/	2/	2/
Krameria parvifolia	(1)	(1)	-	-	-	-	-	-	-	-	-	-
Larrea divaricata	3/	-	1	-	-	-	-	-	-	-	-	-
Lepidium sp.	-	-	-	-	-	3	2	-	-	-	-	-
Leptodactylon pungens	(1)	-	81	-	-	-	-	-	-	-	-	-
Lesquerella sp.	-	-	-	8	13	-	-	-	-	1	3	1
Lycium andersonii	-	(1)	-	-	-	-	-	-	-	-	-	-
Mortonia utahensis	-	-	-	-	-	-	-	-	-	16	-	3
Opuntia sp.	-	-	-	1	-	-	-	-	-	1	-	-
Oryzopsis hymenoides	-	-	1	-	25	3	4	1	-	1	1	1
Penstemon cf. *petiolatus*	-	-	-	-	-	-	-	-	-	-	-	4
Petrophytum caespitosum	-	-	-	7	12	150	51	3	6	207	303	57
Pinus monophylla	-	-	-	631	2/	-	-	-	-	-	-	-
Pleurocoronis pluriseta	-	-	-	-	-	-	-	8	-	-	-	-
Poaceae undet.	-	-	27	3	1	2	2	-	4	-	1	-
Prunus fasciculata	(1)	(3)	103	-	-	-	-	-	-	-	-	-
Purshia tridentata	-	-	-	-	-	-	-	1	-	1	-	-

Table 20.--*Plants from the Specter Range (Spc) 2 site*--Continued

	Vegetation (relative abundance)		Macrofossil assemblages sample number and count									
	Crest	Ledges and talus	Spc-2(mod)	Spc-2(2)$_1$	Spc-2(2)$_2$	Spc-2(3)	Spc-2(6)	Spc-2(8)	Spc-2(10)	Spc-2(11)$_1$	Spc-2(11)$_2$	Spc-2(12)
Salvia dorrii	(2)	(1)	14	-	-	1	-	-	-	-	-	-
Scopulophila rixfordii	-	(3)	151	-	1	27	11	185	48	81	229	160
Sitanion histrix	-	(1)	-	-	-	-	-	-	-	-	-	-
Sphaeralcea ambigua	(1)	-	-	-	-	-	-	-	-	-	-	-
Sphaeralcea sp.	-	-	9	-	-	-	-	-	-	-	-	-
Stanleya sp.	-	-	-	-	2	21	-	-	-	1	1	-
Stipa arida	(1)	(2)	-	-	-	-	-	-	-	-	-	-
Stipa sp.	-	-	1	-	-	1	-	-	-	-	-	-
Streptanthus sp.	-	-	-	3	-	-	-	-	-	-	-	-
Symphoricarpos longiflorus	-	-	-	224	78	30	34	56	65	39	102	91
Tetradymia sp.	-	-	-	4	1	61	44	1	4	2	57	14
Thamnosma montana	(2)	(1)	4	-	-	-	-	-	-	-	-	-
NISP	-	-	1,268	1,059	306	727	225	314	192	713	1,089	386
N	18	20	24	16	17	19	16	15	12	20	20	16
N_{ts}	14	13	17	11	11	13	11	13	9	14	12	12
IS (to current vegetation)	-	-	72	7	13	19	20	12	21	18	19	13

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[1] Exact chronologic position uncertain, see table 6.

[2] Very abundant (>1,000), not counted.

[3] Species in the vicinity, but occurring more than 30 meters from the site.

Table 21.--*Plants from the Specter Range (Spc) 3 site*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts} , number of species of trees, shrubs, and succulents; IS, Sorenson's index of similarity]

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		Spc-3A(1)	Spc-3A(2)	Spc-3B
Approximate radiocarbon age	-	20,200	1/	28,460
Species				
Ambrosia dumosa	(1)	-	-	-
Amphipappus fremontii	(2)	-	-	-
Aristida sp.	(1)	-	-	-
Artemisia sec. Tridentatae	-	2	36	127
Asteraceae undet.	-	-	19	8
Atriplex confertifolia	(2)	118	9	201
Boraginaceae undet.	-	-	-	1
Brickellia arguta	(3)	-	-	-
B. watsonii	(1)	-	-	-
Buddleja utahensis	(3)	-	-	-
Castilleja sp.	-	-	1	-
Ceratoides lanata	(2)	166	4	21
Cercocarpus intricatus	-	1	62	-
Cheilanthes feei	(X)	-	-	-
Chrysothamnus nauseosus	-	-	3	3
Coleogyne ramosissima	2/	-	16	-
Cowania mexicana	-	-	5	-
Cryptantha cf. pterocarya	-	-	10	-
Cryptantha sp.	(X)	-	15	-
Descurainia sp.	-	-	2	-
Echinocactus polycephalus	(1)	-	-	-
Encelia virginensis	(1)	-	-	-
Ephedra funerea	(1)	-	-	-
E. nevadensis	(1)	-	-	-
Ephedra sp.	-	-	207	-
cf. Eriogonum fasciculatum	-	-	-	1
E. heermannii	-	1	1	-
E. inflatum	(X)	-	-	-
Fendlerella utahensis	-	3	32	17
Forsellesia cf. nevadensis	-	1	4	2
Galium stellatum	(1)	-	-	-
Gilia sp.	-	-	24	2
Grayia spinosa	(2)	3	1	-
Gutierrezia microcephala	(2)	2	1	-
Haplopappus cooperi (or nanus)	-	-	7	2
Juniperus osteosperma	-	3/	3/	3/
Larrea tridentata	2/	-	-	-
Lepidium fremontii	(3)	2	5	2
cf. Leptodactylon pungens	-	-	1	2

Table 21.--*Plants from the Specter Range (Spc) 3 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		Spc-3A(1)	Spc-3A(2)	Spc-3B
Lesquerella sp.	-	1	-	2
Lycium andersonii	(2)	-	-	-
L. pallidum	(2)	-	-	-
Lycium sp.	-	-	1	-
Mirabilis sp.	-	-	2	-
Mortonia utahensis	-	-	-	1
Opuntia cf. *erinacea*	-	-	5	-
Opuntia sp.	-	5	-	-
Oryzopsis hymenoides	(X)	3	2	1
Petrophytum caespitosum	-	12	1	15
Phacelia cf. *rotundifolia*	(X)	-	-	-
Phacelia sp.	-	-	6	-
Plagiobothrys jonesii	(X)	-	-	-
Poa fendleriana	(1)	-	-	-
Poaceae undet.	-	-	5	1
Scopulophila rixfordii	(3)	10	8	114
Sphaeralcea ambigua	(2)	-	-	-
Sphaeralcea sp.	-	2	-	-
Stephanomeria pauciflora	(1)	-	-	-
Stipa arida	(2)	-	-	-
Symphoricarpos longiflorus	-	91	609	162
Tetradymia axillaris	(1)	-	-	-
Thamnosma montana	(1)	-	-	-
Yucca brevifolia	-	-	-	1
Yucca sp.	-	-	3	-
NISP	-	423	1,107	686
N	33	18	33	22
N_{ts}	20	15	22	15
IS (to current vegetation)	-	34	43	17

1/ Contaminated sample, see table 6.

2/ Species in the vicinity, but occurring more than 30 meters from the site.

3/ Very abundant (>1,000), not counted.

Table 22.--*Plants from the Specter Range (Spc) 1 site*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Vegetation (relative abundance)			Macrofossil assemblages sample number and count	
	In wash	On rocks and terrace	On top of ridge	Spc-1(1)	Spc-1(2)
Approximate radiocarbon ages	-	-	-	300±40	100^{+200}_{-100}
Species					
Acamptopappus sphaerocephalus	-	-	(1)	-	-
Ambrosia dumosa	(2)	-	(1)	3	21
A. eriocentra	(1)	-	-	-	-
Amsinckia sp.	-	-	-	1	3
Arabis sp.	(X)	(X)	-	-	-
Aristida glauca	-	(X)	-	-	-
Asteraceae undet.	-	-	-	22	21
Atriplex canescens	(3)	(1)	-	625	140
A. confertifolia	-	-	-	30	-
Boraginaceae undet.	-	-	-	2	5
Brickellia arguta	-	(3)	-	8	2
B. desertorum	-	(2)	-	-	-
Bromus rigidus	(X)	-	-	-	-
B. rubens	(X)	(X)	-	-	10
Buddleja utahensis	-	(1)	-	4	29
Castilleja sp.	-	-	(X)	-	-
Ceratoides lanata	-	(1)	-	40	22
Chorizanthe rigida	-	-	1/	-	-
Chrysothamnus viscidiflorus	-	-	-	1	-
Coleogyne ramosissima	-	-	1/	-	1
Coryphantha vivipara	-	-	(1)	-	-
Cryptantha sp.	(X)	-	(X)	-	-
Cuscuta sp.	(1)	-	-	1	-
Descurainia sp.	-	-	-	1	2
Dichelostemma pulchellum	(X)	-	-	-	-
Echinocactus polycephalus	-	-	(1)	-	-
Echinocereus sp.	-	-	-	-	1
Encelia virginensis	-	-	1/	-	-
Ephedra nevadensis	(3)	-	(1)	-	-
E. torreyana	-	(1)	-	-	-
Ephedra sp.	-	-	-	77	70
Eriogonum heermannii	-	(4)	-	3	4
E. fasciculatum	-	-	-	5	8
E. inflatum	-	(X)	-	-	-

Table 22.--*Plants from the Specter Range (Spc) 1 site*--Continued

	Vegetation (relative abundance)			Macrofossil assemblages sample number and count	
	In wash	On rocks and terrace	On top of ridge	Spc-1(1)	Spc-1(2)
Erioneuron pulchellum	-	(1)	-	-	-
Euphorbia sp.	-	-	-	2	1
Festuca octoflora	-	-	(X)	-	-
Gilia sp.	(X)	(X)	-	-	6
Grayia spinosa	-	-	(1)	35	55
Gutierrezia microcephala	-	(1)	-	75	171
Hilaria rigida	-	-	(X)	-	-
Hymenoclea salsola	(3)	-	-	15	84
Krameria grayi	-	-	1/	1	-
Larrea divaricata	(4)	-	-	87	576
Lepidium fremontii	(1)	-	-	34	23
Lepidium sp.	(X)	-	-	-	-
Leptodactylon pungens	-	-	(1)	-	-
Lycium andersonii	(2)	(2)	-	-	-
L. pallidum	(1)	-	-	-	6
Lycium sp.	-	-	-	34	23
Machaeranthera tortifolia	(1)	-	(1)	-	-
Mirabilis bigelovii	-	(X)	-	12	48
Opuntia basilaris	-	-	(1)	-	-
Opuntia sp. (not *O. basilaris*)	-	-	(1)	-	-
Oryzopsis hymenoides	-	-	(X)	1	5
Oxytheca perfoliolata	(X)	-	-	-	-
Phacelia sp.	(X)	-	-	2	-
Plantago sp.	-	-	-	1	2
Poaceae undet.	-	-	-	8	8
Psorothamnus fremontii	-	-	(1)	2	6
Salazaria mexicana	(1)	-	(1)	1	3
Salsola kali	(X)	-	-	-	-
Scopulophila rixfordii	-	(X)	-	-	-
Sphaeralcea ambigua	(1)	(2)	-	8	57
Stanleya pinnata	(1)	-	-	-	-
Stipa sp.	-	(X)	-	-	-
Thamnosma montana	(1)	-	(1)	16	3
Yucca schidigera	-	-	1/	-	-
Yucca sp.	-	-	-	6	55
NISP	-	-	-	1,165	1,469
N	26	19	18	35	34
N_{ts}	11	11	13	25	24
IS (to current vegetation, combined)	-	-	-	73	70

1/Species in the vicinity, but occurring more than 30 meters from the site.

Table 23.--*Plants from the Eleana Range (ER) 2 site*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; AT, arboreal taxa; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count								
		ER-2(1)	ER-2(2)	ER-2(3)	ER-2(4)	ER-2(5)	ER-2(6)	ER-2(7)	ER-2(9)	ER-2(10)
Approximate radiocarbon age		10,600	11,700	13,200	14,090	14,300	14,600	14,800	15,900	17,100
Species										
Agropyron sp.	(X)	-	-	-	3	-	-	-	-	-
Arceuthobium sp.	-	-	-	-	19	-	-	-	-	-
Aristida sp.	(X)	-	-	-	-	-	-	-	-	-
Artemisia nova	(1)	-	-	-	-	-	-	-	-	-
Artemisia sec. Tridentatae	-	30	45	153	178	317	100	139	111	172
Asteraceae undet.	-	82	21	146	335	95	41	71	43	25
Atriplex canescens	(4)	6	-	-	-	-	-	-	-	-
Boraginaceae undet.	-	24	41	29	4	23	9	13	8	8
Brickellia californica	(1)	-	-	-	-	-	-	-	-	-
Brickellia sp.	-	2	2	-	-	-	-	-	-	-
Bromus *tectorum*	(X)	-	-	-	-	-	-	-	-	-
Castilleja sp.	-	5	-	-	2	1	-	-	-	-
Cercocarpus ledifolius	-	114	-	390	106	25	1	6	139	10
Chamaebatiaria millefolium	-	4	11	14	56	90	61	54	20	24
Chrysothamnus nauseosus	(2)	15	19	44	48	102	24	29	55	35
C. *viscidiflorus*	(1)	9	2	82	184	111	43	109	24	20
Cirsium sp.	-	1	-	-	-	-	-	-	-	-
Cowania mexicana	1/	-	-	-	-	-	-	-	-	-
Cryptantha confertiflora	(X)	-	-	-	-	-	-	-	-	-
Cryptantha sp.	-	-	2	-	1	-	-	-	-	-
Echinocereus triglochidiatus	1/	-	-	-	-	-	-	-	-	-
Ephedra nevadensis	(1)	-	-	-	-	-	-	-	-	-
E. *viridis*	(2)	-	-	-	-	-	-	-	-	-

Table 23.--*Plants from the Eleana Range (ER) 2 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count								
		ER-2(1)	ER-2(2)	ER-2(3)	ER-2(4)	ER-2(5)	ER-2(6)	ER-2(7)	ER-2(9)	ER-2(10)
Eriogonum fasciculatum	1/	-	-	-	23	-	-	-	-	-
E. inflatum var. deflatum	(X)	-	-	-	-	-	-	-	-	-
E. microthecum	(X)	-	-	-	-	-	-	-	-	-
Eriogonum sp.	-	3	5	-	-	5	1	-	1	-
Euphorbia sp.	-	1	3	1	-	-	-	-	-	-
Festuca sp.	(X)	-	-	-	-	-	-	-	-	-
Forsellesia nevadensis	1/	-	-	-	-	-	-	-	-	-
Gilia sp.	-	-	-	-	1	-	-	1	-	-
Haplopappus nanus	(1)	231	131	108	106	87	67	53	19	-
Heterotheca villosa	(X)	-	-	-	-	-	-	-	-	-
Hilaria jamesii	(X)	-	-	-	-	-	-	-	-	-
Holodiscus microphyllus	-	4	-	7	20	5	2	11	2	1
Juniperus osteosperma	1/	2/	270	1	-	-	-	-	-	-
Lepidium sp.	-	-	-	1	-	-	-	-	-	-
cf. Leptodactylon pungens	-	32	1	-	2	5	2	2	15	3
Lesquerella sp.	-	9	-	1	-	1	3	-	1	1
Linum lewisii	(X)	-	-	-	-	-	-	-	-	-
Lupinus cf. argenteus	-	7	6	12	86	256	170	191	145	212
Machaeranthera canescens	(2)	-	-	-	-	-	-	-	-	-
Machaeranthera sp.	-	1	-	-	-	1	-	-	-	-
Opuntia erinacea	1/	586	576	-	-	-	-	-	-	-
Opuntia sp.	-	-	-	-	1	-	-	-	-	-
Oryzopsis hymenoides	(X)	14	6	7	27	17	18	15	11	15
Penstemon sp.	1/	1	-	2	-	-	3	21	2	2
Petradoria pumila	1/	1	3	2	6	2	-	-	8	-
Phacelia mustelina	(X)	-	-	-	-	-	-	-	-	-
Phacelia sp.	(X)	-	-	-	-	-	-	-	-	-
Pinus flexilis	-	6	22	2/	2/	2/	2/	2/	2/	2/
P. monophylla	1/	95	254	-	-	-	-	-	-	-
Poaceae undet.	-	58	127	116	46	203	302	164	108	300

Table 23.--*Plants from the Eleana Range (ER) 2 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count								
		ER-2(1)	ER-2(2)	ER-2(3)	ER-2(4)	ER-2(5)	ER-2(6)	ER-2(7)	ER-2(9)	ER-2(10)
Prunus fasciculata	1/	-	-	-	-	-	-	-	-	-
Purshia tridentata	-	65	40	-	24	12	18	4	1	-
Quercus gambelii	1/	-	-	-	-	-	-	-	-	-
Rhus trilobata	1/	-	-	-	-	-	-	-	-	-
Ribes cf. *velutinum*	-	2	-	-	2	3	-	-	-	-
Salvia dorrii	-	99	88	-	-	-	-	-	-	-
Senecio multilobatus	(X)	-	5	-	-	-	-	-	-	-
Sitanion hystrix	(X)	-	-	3	-	-	-	-	-	-
Sphaeralcea cf. *ambigua*	1/	1	1	-	-	-	-	-	-	-
Stanleya pinnata	(1)	-	-	-	-	-	-	-	-	-
Stipa sp.	(X)	-	2	-	-	1	1	-	-	-
Symphoricarpos longiflorus	1/	-	-	-	-	-	-	-	-	-
Symphoricarpos sp.	-	67	33	-	-	-	-	-	-	-
Tetradymia canescens	(3)	-	-	-	-	-	-	-	-	-
Tetradymia sp.	-	6	3	67	183	208	222	186	214	160
NISP	-	1,521	1,719	1,186	1,461	1,570	1,088	1,069	927	988
NISP-AT	-	1,480	1,173	1,185	1,461	1,570	1,088	1,069	927	983
N	28	33	27	20	25	24	20	17	20	16
N_{ts}	10	23	18	13	17	15	12	13	12	10
IS[3]	-	79	86	58	59	48	45	43	45	40

[1] Species in the vicinity, but more than 30 meters from the site.

[2] Very abundant (>1,000), not counted.

[3] Includes those fossil trees, shrubs, and succulents that now occur in the vicinity, but more than 30 meters from the site.

Table 24.--*Plants from the Eleana Range (ER) 3 site*

[Relative abundance values for modern vegetation are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N_{ts}, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count										
		ER-3(mod)	ER-3(2)	ER-3(3)	ER-3(4)	ER-3(6)	ER-3$(7)_2$	ER-3$(8)_2$	ER-3$(8)_3$	ER-3(9)	ER-3(10)	ER-3(13)
Approximate radiocarbon age	-	-	1/	38,700	1/	1/	45,000	1/	37,800	1/	1/	1/
Species												
Artemisia nova	(2)	-	-	-	-	-	-	-	-	-	-	-
A. tridentata	(3)	-	-	-	-	-	-	-	-	-	-	-
Artemisia sec. Tridentatae	-	19	346	358	150	210	456	328	293	129	167	85
Asteraceae undet.	-	-	-	-	247	10	23	-	10	2	1	340
Atriplex canescens	(4)	387	-	-	-	-	-	-	-	-	-	-
A. confertifolia	-	-	-	-	-	-	-	-	-	-	-	4
Boraginaceae undet.	-	10	19	32	10	13	30	34	59	4	1	8
Brickellia californica	(1)	-	-	-	-	-	-	-	-	-	-	-
B. microphylla	(1)	-	-	-	-	-	-	-	-	-	-	-
Bromus tectorum	(X)	-	-	-	-	-	-	-	-	-	-	-
Ceratoides lanata	-	-	-	-	-	-	-	-	-	-	-	2
Cercocarpus ledifolius	-	-	200	195	294	260	231	198	316	224	516	120
Chamaebatiaria millefolium	-	-	-	4	-	-	-	-	1	3	6	1
Chenopodium sp.	-	-	-	-	1	-	-	-	-	-	-	-
Chrysothamnus nauseosus	(1)	-	-	-	-	-	-	-	-	-	-	-
C. viscidiflorus	(2)	-	156	124	111	57	84	185	121	118	139	67
Cirsium sp.	-	-	-	-	-	1	-	-	-	-	-	-
Cowania mexicana	(1)	153	-	-	-	-	-	-	-	-	-	-
Cryptantha confertiflora	(X)	-	-	-	-	-	-	-	-	-	-	-
Cryptantha sp.	-	1	-	-	1	-	-	-	-	1	-	-
Ephedra torreyana	(1)	-	-	-	-	-	-	-	-	-	-	-
E. viridis	(2)	-	-	-	-	-	-	-	-	-	-	-
Ephedra sp.	-	16	-	-	5	-	-	72	11	-	-	-

Table 24.--*Plants from the Eleana Range (ER) 3 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count										
		ER-3(mod)	ER-3(2)	ER-3(3)	ER-3(4)	ER-3(6)	ER-3(7)$_2$	ER-3(8)$_2$	ER-3(8)$_3$	ER-3(9)	ER-3(10)	ER-3(13)
Eriogonum caespitosum	(1)	-	-	-	-	-	-	-	-	-	-	-
E. fasciculatum	(1)	-	-	-	-	-	-	-	-	-	-	-
E. inflatum	(X)	-	-	-	-	-	-	-	-	-	-	-
E. microthecum	(1)	-	-	-	-	-	-	-	-	-	-	-
Festuca sp.	(X)	-	-	-	-	-	-	-	-	-	-	-
Forsellesia nevadensis	-	-	-	-	-	-	-	1	-	-	-	-
Gilia sp.	-	2	-	-	-	-	-	-	-	-	-	-
Grayia spinosa	-	-	-	41	-	1	-	-	3	-	-	-
Haplopappus nanus	(2)	12	21	13	18	5	30	20	12	12	48	-
Heterotheca vilosa	(X)	-	-	-	-	-	-	-	-	-	-	-
Holodiscus microphyllus	-	-	21	67	14	1	9	24	10	4	-	-
Juniperus osteosperma	(1)	75	131	723	222	128	380	123	194	51	79	9
Lepidium sp.	-	-	-	-	-	-	-	-	-	-	-	1
Leptodactylon pungens	(1)	-	-	-	-	-	-	-	-	-	-	-
Lesquerella sp.	-	-	-	19	7	1	6	14	14	39	2	-
Linum lewisii	(X)	-	-	-	-	-	-	-	-	-	-	-
Linum sp.	-	5	-	-	-	-	-	-	-	1	-	-
Lupinus cf. argenteus	-	-	-	-	-	-	-	-	-	-	-	399
Machaeranthera canescens	(1)	-	-	-	-	-	-	-	-	-	-	-
Opuntia erinacea	2/	1	4	4	3	2	-	33	46	-	-	-
Opuntia sp.	-	-	-	-	-	-	17	-	-	2	12	14
Oryzopsis hymenoides	(X)	26	2	2	14	9	-	3	-	81	10	297
Penstemon sp.	-	1	-	1	-	1	-	-	-	-	-	-
cf. Petradoria pumila	-	-	-	-	12	-	-	-	-	-	-	-
Phacelia sp.	(X)	3	-	-	-	-	-	-	-	-	-	-
Pinus flexilis	-	3	37	-	735	828	5	36	167	910	1,443	807
P. monophylla	(2)	79	-	-	-	-	-	-	-	-	-	1
Pinus sp.	-	-	-	-	-	-	-	-	-	-	-	1
Poaceae undet.	-	177	4	17	12	9	6	15	4	9	18	53
Purshia tridentata	-	1	1	-	-	-	-	-	-	-	-	-

Table 24.--*Plants from the Eleana Range (ER) 3 site*--Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count										
		ER-3(mod)	ER-3(2)	ER-3(3)	ER-3(4)	ER-3(6)	ER-3(7)$_2$	ER-3(8)$_2$	ER-3(8)$_3$	ER-3(9)	ER-3(10)	ER-3(13)
Quercus gambelii	2/	2	-	-	-	-	-	-	-	-	-	-
Rhus trilobata	(1)	5	-	-	-	-	-	-	-	-	-	-
Ribes cf. velutinum	-	-	1	-	1	-	-	-	1	-	-	-
Ribes sp.	-	-	-	1	-	4	-	-	-	-	-	-
Salvia columbariae	(X)	-	-	-	-	-	-	-	-	-	-	-
S. dorrii	-	-	-	-	-	-	-	-	-	-	-	1
Senecio multilobatus	(X)	-	-	-	-	-	-	-	-	-	-	-
Sphaeralcea sp.	(1)	17	-	-	-	-	-	-	-	-	-	1
Stanleya pinnata	(1)	-	-	-	-	-	-	-	-	-	-	-
Stipa sp.	(X)	-	-	-	-	-	-	-	-	1	-	-
Symphoricarpos longiflorus	(2)	-	-	-	-	-	-	-	-	-	-	-
Symphoricarpos sp.	-	4	-	27	79	39	28	135	101	97	132	86
Tetradymia sp.	-	-	125	18	78	37	81	126	71	92	100	26
NISP	-	999	1,068	1,646	2,014	1,616	1,386	1,347	1,434	1,780	2,674	2,322
N	33	22	14	17	21	19	14	16	19	19	15	20
N_{ts}	20	14	11	12	14	12	10	12	14	11	10	16
IS (to current vegetation)	-	71	32	38	47	38	40	50	47	39	40	44

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[1] Age uncertain, see table 6.

[2] Species in the vicinity, but more than 30 meters from the site.

Table 25.--*Plants from the Eureka View (EV) fossil locality*[1/]

[Macrofossil data are presented in terms of relative abundance classes: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; 0, less than five fragments, a possible contaminant. B.P., before present; N, total number of plant taxa; N_p, total number of woody perennials; IS, Sorensen's index of similarity between macrofossil assemblage and the modern plant community (using N); %, percent. Data from Spaulding (1980)]

	Relative abundance of species in macrofossil assemblage									
	EV-1	EV-2A	EV-2B	EV-2C	EV-3	EV-4(1)	EV-4(2)	EV-4(3)	EV-5A	EV-5B
Approximate radiocarbon age	2,635± 140 B.P.	No date	1,580± 140 B.P.	3,930± 180 B.P.	535± 150 B.P.	5,595± 210 B.P.	6,795± 190 B.P.	5,435± 220 B.P.	14,720± 530 B.P.	8,330± 250 B.P.
Species										
Ambrosia dumosa[2/]	3	1	-	-	-	2	2	1	-	-
Amphipappus fremontii[2/]	-	-	2	-	2	-	-	-	-	-
Amsinckia intermedia	-	-	-	-	-	1	-	-	1	1
A. tesselata	2	2	-	-	-	-	-	-	-	-
Amsinckia sp.[2/]	-	-	-	1	-	-	-	-	-	-
Aristida adscensionis[2/]	-	-	-	-	-	-	-	-	-	-
Artemisia sec. Tridentatae	0	-	-	-	-	-	1	-	2	-
Atriplex confertifolia[3/]	5	4	5	4	3	5	5	4	4	5
Brickellia arguta[2/]	-	-	-	-	-	-	-	-	-	-
Cheilanthes feei[2/]	-	-	-	-	-	-	-	-	-	-
Chorizanthe cf. *brevicornu*	-	1	1	-	-	-	-	-	-	-
Chorizanthe cf. *rigida*[2/]	1	1	1	1	-	-	-	-	-	-
cf. *Chrysothamnus* sp.	-	-	-	-	-	-	-	-	2	-
Cryptantha sp.	-	-	2	-	2	-	-	-	1	-
Echinocactus polycephalus[2/]	2	0	1	1	-	-	-	-	-	-
Encelia virginensis	-	-	-	2	-	3	3	4	0	-
Ephedra nevadensis[2/]	-	-	-	-	-	-	-	-	-	-
Ephedra cf. *viridis*	-	-	-	-	-	-	-	-	3	-
Ephedra sp.	-	1	2	-	-	-	-	-	-	3
Eriogonum inflatum[2/]	-	1	-	-	-	-	-	-	-	-
E. fasciculatum[2/]	-	2	2	-	1	-	-	-	-	-
Eriogonum sp.	1	-	1	-	-	-	-	-	1	-
Erioneuron pulchellum[2/]	1	1	3	2	2	2	1	2	-	-

Table 25.--*Plants from Eureka View (EV) fossil locality*--Continued[1/]

	Relative abundance of species in macrofossil assemblage									
	EV-1	EV-2A	EV-2B	EV-2C	EV-3	EV-4(1)	EV-4(2)	EV-4(3)	EV-5A	EV-5B
Eucnide urens[2/]	-	-	-	-	-	-	-	-	-	-
Euphorbia sp.	-	-	-	-	-	-	1	-	2	-
Festuca sp.	-	2	-	-	-	-	-	-	-	1
Foresellesia nevadensis	-	-	-	-	-	-	-	-	1	-
Gilia sp.[2/]	1	1	1	-	1	-	-	-	-	1
Gutierrezia microcephala[2/]	-	-	1	-	-	-	-	-	-	-
Haplopappus brickellioides[2/]	-	-	-	1	2	1	3	2	-	1
H. laricifolius[2/]	-	-	-	-	-	-	-	-	-	-
Haplopappus sp.	1	-	-	-	-	-	-	-	-	-
Hecastocleis shockleyi	-	-	-	-	-	-	-	-	3	-
Juniperus osteosperma	-	-	-	-	-	0	-	-	5	-
Larrea tridentata[3/]	4	5	5	2	5	-	-	0	-	-
Lepidium cf. *fremontii*	2	1	1	-	-	1	1	2	1	2
Lepidium sp.	-	-	-	-	1	-	-	-	-	-
Lycium sp.	-	-	-	-	-	2	2	1	-	-
cf. *Machaeranthera* sp.	-	-	-	-	-	-	-	-	1	-
Mirabilis sp.	-	-	-	-	-	1	-	-	1	1
Nama sp.[2/]	-	-	-	-	-	-	-	-	-	-
Nicotiana trigonophylla[2/]	-	-	-	1	-	-	-	-	-	-
Opuntia oasilaris	1	1	3	3	-	3	4	4	-	-
O. echinocarpa	2	-	-	-	-	-	-	-	-	-
Opuntia sp.	-	-	2	3	2	2	-	-	-	-
Penstemon sp.	-	-	1	1	-	-	-	-	1	-
Peucephyllum schottii	-	-	2	1	2	-	-	-	-	-
Phacelia crenulata[2/]	-	-	-	-	-	-	-	-	-	-
Phacelia sp.	1	1	1	-	-	1	2	1	-	-
Physalis cf. *crassifolia*[2/]	3	1	1	1	-	1	-	-	1	1
Pinus cf. *flexilis*	-	-	-	-	-	-	-	-	1	-
Psorothamnus fremontii	-	-	3	-	-	1	3	1	-	1

Table 25.--*Plants from Eureka View (EV) fossil locality*--Continued[1]

		Relative abundance of species in macrofossil assemblage									
		EV-1	EV-2A	EV-2B	EV-2C	EV-3	EV-4(1)	EV-4(2)	EV-4(3)	EV-5A	EV-5B
Salvia dorrii		-	-	-	-	-	-	-	-	1	-
cf. Sclerocactus sp.		-	-	-	-	-	-	-	-	1	-
Scopulophila rixfordii[2]		1	-	-	1	1	1	2	1	-	1
Sphaeralcea sp.		-	-	-	-	-	-	-	-	1	-
Stipa sp.[2]		-	1	2	1	1	-	-	1	-	-
Symphoricarpos cf. longiflorus		-	-	-	-	-	-	-	-	1	-
Tidestomia oblongifolia		1	-	-	1	-	-	-	-	-	-
Viguiera reticulata[2]		3	-	-	-	2	-	-	-	-	-
N	(26)	19	18	22	18	14	16	13	12	22	12
N_p	(15)	12	8	13	11	9	11	10	10	14	6
N_p/N (100)	(58%)	63%	44%	59%	61%	64%	69%	77%	77%	64%	50%
IS	-	62	64	58	54	50	38	31	41	17	37

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[1] In the northern Eureka Valley, Inyo County, California (1,390 to 1,555 meters; T. 7 S., R. 38 E., S½NW¼ sec. 23; Soldier Pass, California-Nevada 15' quadrangle).

[2] Plant species presently at site.

[3] Dominant plant species presently at site.

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